المملكة العربية السعودية
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جامعة أم القرى
كلية العــلوم التطبيقيـــة

دراسة عن كواشف الأثر النووي واستخدامها في

قياس المستويات الإشعاعية
في مكة المكرمة

رسالة مقدمة إلى قسم الفيزياء بكلية العلوم التطبيقية كجزء من متطلبات الحصول على درجة الماجستير في الفيزياء

مقدمة من

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تلخيص

تم في الدراسة المقدمة في هذه الرسالة بناء نظام للكشف عن غاز الرادون ومخلفاته وقياس تركيزه باستخدام كواشف الحالة الصلبة لقياس الأثر النووي Solid State Nuclear Track Detectors SSNTDs من نوع CR-39 ، وكذلك بناء نظام للنخر الكهرو كيميائي Electro-Chemical Etching (بما في ذلك مصدر الجهد العالي) لإظهار الآثار النووية . وقد شملت الدراسة العملية إيجاد أفضل أبعاد لنظام الكشف الأسطواني المستخدم Can technique ، وقد وجد أن أفضل قطر هو 7cm وأفضل ارتفاع هو 4cm . كما تم إيجاد أفضل ظروف لعملية النخر الكهرو كيميائي وهي على النحو التالي : 5 Kvolts لقيمة الجهد المستخدم ، 2.5 KHz لقيمة التردد ، كما وجد أن أفضل زمن للنخر هو ساعتان . ويقصد بأفضل الظروف هي التي تعطي أعلى كثافة وأفضل شكل للآثار النووية . كما تم قياس الزاوية الحرجة لمادة الكاشف المستخدم وقد وجد أنها تساوي 10^{o} . وقد تمت مقارنة نتائج القياس باستخدام النظام الذي تم بناؤه بنتائج القياسات التي تم الحصول عليها باستخدام نظام للكشف عن الرادون تم تصميمه ومعايرته بواسطة الهيئة الوطنية البريطانية للحماية الإشعاعية ويستخدم كاشف CR-39 . كما تمت المقارنة مع نظام الكشف التابع لكلية الهندسة بجامعة الملك عبد العزيز بجدة والذي يستخدم طريقة الترسيب على الفحم الحجري . وفي كلا الحالتين وجد أن هناك توافقا في نتائج القياسات .

تم بعد ذلك إجراء القياسات الميدانية لتركيز غاز الرادون داخل المنازل (غرف النوم) في مختلف أحياء مكة المكرمة وقد وجد أن متوسط التركيز هو $56 \pm 23\ Bq/m^3$ ، كما تم إجراء القياسات داخل بعض الأنفاق ووجد أن متوسط التركيز هو $52 \pm 13\ Bq/m^3$. أما داخل بعض مساجد المشاعر المقدسة فقد كان متوسط التركيز $40 \pm 22\ Bq/m^3$. هذه المستويات أقل من الحدود الدنيا المسموح بها دوليا والتي تقع في المدى $200\text{-}600 Bq/m^3$ كما تم تكرار القياسات صيفا وشتاءا في بعض المواقع لمعرفة تأثير التغير الطبيعي الفصلي لدرجة الحرارة على غاز الرادون . وقد وجد أن التركيز يزداد قليلا في فصل الشتاء عما هو عليه في فصل الصيف . وقد تبين أن تركيز غاز الرادون يعتمد على حجم الموقع ومساحة الشبابيك وعلى نظام التكييف وطريقة التهوية المتبعة .

وقد تم استخدام نظام الكشف في إجراء بعض الدراسات المبدئية الكشفية Feasibility studies التي تحتاج إلى مزيد من الدراسات التفصيلية المتأنية الشاملة ، ومنها :

(١) تقدير تركيز الرادون داخل خزانات المياه الأرضية بالمنازل لأنها محفورة داخل الأرض ومغطاة بطبقة سميكة من الخرسانة المسلحة وعادة ما تكون عديمة التهوية . وقد وجد أن متوسط التركيز 71 ± 19 Bq/m^3 وهي مرتفعة مقارنة بغرف النوم في نفس المنازل التي تمت دراستها 46 ± 17 Bq/m^3 ، ولكنها تبدو أقل مما هو متوقع داخل هذه الخزانات ، وقد يعزى ذلك إلى أن وجود الماء يعيق غاز الرادون من الوصول إلى مادة الكاشف .

(٢) إيجاد تركيز نشاط اليورانيوم في الصخور وتحديد محتوى هذه الصخور من مادة اليورانيوم ، وقد وجد أنها على التوالي 23.7 ± 9Bq/kg و 1.9 ± 0.7 ppm .

(٣) إيجاد تركيز نشاط الراديوم-٢٢٦ في التربة وتحديد محتوى التربة من مادة الراديوم ، وقد وجد أنها على التوالي 49.2 ± 19Bq/kg و 3.9 ± 1.5 ppm .

(٤) مراقبة انبعاث الرادون من الأرض للتعرف على أماكن وجود الشقوق والتصدعات الأرضية .

كما تم قياس معدل الجرعة الإشعاعية الناتجة عن أشعة جاما خارج المنازل باستخدام جهاز المسح الإشعاعي الذي يستخدم كاشف جايجر مولر ، وقد وجد أن متوسط الجرعة السنوية المكافئة الفعالة يساوي 0.46 mSv/year .

وتجدر الإشارة هنا إلى الباحثة قامت بإجراء كافة التجارب التي أجريت داخل المختبر ، كما قامت بتثبيت بعض أنظمة الكشف داخل بعض المنازل ، أما أنظمة الكشف التي ثبتت في الأماكن العامة فقد تم تثبيتها بواسطة فنيي قسم الفيزياء .

Kingdom of Saudi Arabia
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A Study of The Nuclear Track Detectors and The use of Them in

Natural Radioactivity Measurements in Makkah

Submitted to the Physics Department as Part Fulfillment For Master Degree in Physics

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Synopsis

In the present work, can technique radon detection system using CR-39 Solid State Nuclear Track Detectors SSNTDs was built. The resultant tracks were revealed by using an Electro-Chemical Etching (ECE) system which was also built in the physics department, and they were counted using an optical microscope. An optimization investigation was carried out to find the best values for the involved parameters such as can height and diameter, ECE voltage, frequency and time. The optimum values are those values which give the highest track density and the best shape for them .The following values were found: 7cm and 4cm for the can height and diameter respectively, 5 k V , 2.5 k Hz, 2 hrs for the ECE voltage, frequency and etching time respectively. The critical angle for CR-39 detector was experimentally determined, and was found to be 10^{o}. For verification reasons, the results of the local detection system were compared with two types of radon dosimeters; one of them was designed and calibrated by the British National Radiation Protection Board (NRPB). It was made up of plastic and has the shape of half sphere with circular base 7 cm diameter and 4 cm height. It used CR-39 as a detection material . The other one belongs to the faculty of engineering in King Abdulaziz University. It depended on perception on charcoal. The results of the two types of measurements were in good agreement with the results taken by our local system.

Indoor radon measurements inside bedrooms were performed in fifteen various districts in Makkah. The average value was 56 ±23 Bq/m^3. Measurements were also carried out inside five tunnels and inside Mashayer mosques.

The average values were 52 ±13 Bq/m^3 and 40 ±22 Bq/m^3 respectively. These values are far below the lower international permissible limit, which lies in the range 200-600 Bq/m^3. The effect of seasonal temperature changes was tested by measuring radon concentration in summer and in winter. As expected, the concentration was slightly increased in winter. The parameters which play the most important role in radon concentration are the room volume and windows size, and the air conditioning and ventilation methods.

The detection system developed in this study was used to perform some feasibility studies such as :

(1) the estimation of radon concentration inside ground water reservoirs in the houses . They are expected to have large concentration , because they are dug inside the ground , covered with thick layer of concrete and rarely ventilated . The measurements were carried out on three different places and the average value was 71±19 Bq/m^3 which is slightly higher than the concentration measured inside bedrooms of the same houses , but it is not as high as expected. This could be attributed to the fact that the presence of water and water vapor obstructs radon gas from reaching the detectors , radon can be dissolved in water .

(2) U^{238} activity concentration in three rock samples and uranium content in these rocks were found to be 23.7 ±9 Bq/kg and 1.9 ±0.7 ppm respectively .

(3) Ra^{226} activity concentration in three soil samples and radium content in the soil were found to be 49.2 ±19 Bq/kg and 3.9 ± 1.5 ppm respectively .

(4) Monitoring of radon emanated from the ground to test the presence of cracks in the earth crust .

The radiation dose equivalent due to outdoor gamma radiation was measured using a Geiger – Muller survey meter . The average annual effective dose equivalent was 0.46 m Sv/year .

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Fayza

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Chapter One

General Introduction

1-1 Nuclear radiation and Its Natural Sources :

Nuclear radiation exists everywhere in the world. Certain types of them reach the earth from the outer space, they are known as ***cosmic rays*** . Other types are produced from the radioactive decay of some isotopes present in the soil or rocks or in the building materials used in that area . Cracks in the earth crust is a major source of natural radioactivity. The presence of research centers, medical, industrial and agricultural establishments, which use radioactive sources in their applications, contribute to the environmental level of radioactivity. The type of nuclear radiation in any area depends on the nature of that area. However, alpha particles from radon gas, which accumulates in badly ventilated areas, and gamma rays generated in various decay processes are the most common types of radiation. These two types of radiation can be harmful to human being when total accumulated exposure exceeds permissible limits.

Although governments and societies take all required precautions and follow the international safety regulations, the above mentioned sources (if present) play an important role in forming the radiation level of the local area which in

Turn determines the radiation dose to which the population of that area is exposed. Hence, it is essential to know the radiation level and to monitor any changes occurring and make suitable suggestions to maintain a healthy environment for the population.

Makkah is a valley surrounded by mountains from all sides. The rocks of these mountains contain several radioisotopes. For this reason, we carried out a study of radon gas and gamma radiation to determine the actual radioactive level in the air, soil and inside the houses of Makkah .

1-2 Expressions, Nominations and Terminology:

In this section we introduce the expressions and terminology which will be used throughout this thesis. They are available in many textbooks such as ref.1.

Radiation Activity C:

It is represented by the number of disintegrations per second and it is measured in ***Curies*** ***(Ci)*** which is defined as the quantity of any radioactive material which gives 3.7×10^{10} disintegration/second. It is replaced by the SI unit, the Becquerel ***(Bq)*** defined as the quantity of any radioactive material which gives 1 disintegration/second; so that we have:

1 Ci = 3.7×10^{10} disintegration/second

1 Bq = 1 disintegration/second

Radiation Absorbed Dose D :

It is the total energy absorbed from any type of radiation per unit mass of the absorber . It does not depend on the absorbing medium , it only depends on the absorbed energy . Its historical unit is the ***rad*** in the C G S system which is defined as 100 ergs/gram . The rad is replaced by SI eqivalent unit , the gray (Gy) defined as 1Joul/kilogram , so that :

1 Gy = 100 rad .

Radiation Dose Equivalent H :

It is defined as the amount of radiation of any type which causes the same effect when it enters any biological system as medium energy x-rays (200 kV) or Co^{60} γ rays . It does not depend on the absorbing medium or the type of radiation . It only depends on the biological effects in the medium and is given by the relation :

$$H = D \times QF$$

where QF is called the quality Factor and is given in table 1-1 [1] .

The unit of H is the ***rem*** when D is measured in rads ; and the unit ***Sievert Sv*** when D is measured in Gy so that :

1 Sv = 100 rem

Table 1-1 : Values of the quality factors for various types of radiation [1,2]

Type of radiation and energy range	QF
Photons , all energies	1
Electrons & muons , all energies	1
Protons , except recoil with E>2MeV	5
Alpha Particles , Fission Fragments & Heavy Particles	20
Neutrons with energy E	$5+17\exp[-(\ln 2E)^2/6]$

Effective Radiation Dose Equivalent H_E:

It is defined as the quantity of radiation of any type which causes the same effect in any organ of any biological system as medium energy x-rays (200 kV) or Co^{60} γ rays. It does not depend on the absorbing medium nor the type of radiation nor the biological organ . It is given by the relation : $H_E = \Sigma_T W_T H_T$ where W_T is a harm weighting factor and is given in table 1-2 [2] . If the human body is exposed to regular radioactive potential and if the effective radiation equivalent dose per year is H_O , then the annual effective radiation equivalent dose for any particular organ should not exceed the value H_O , i.e. : $\Sigma_T W_T H_T \leq H_O$

Table 1-2 : Estimated Values of the Hazard Weighting Factor for The Different Types of Radiation on Different Organs [1,2]

Organ	Factor	Organ	Factor
Gonads	0.2	Liver	0.05
Red bone marrow	0.12	Oesophagus	0.05
Colon	0.12	Thyroid	0.05
Lung	0.12	Skin	0.01
Stomach	0.12	Bone surface	0.01
Bladder	0.05	Remainder	0.05
Breast	0.05		

Radon Gas Concentration :

Since radon gas is radioactive and its atoms decay by emitting alpha particles, so its concentration (number of atoms per unit volume) is given in terms of its radioactivity, i.e. pico curie per liter pCi/L of air or Becquerel/m^3. Radon daughters concentration is expressed in a unit called the ***Working Level WL*** [3] .

The Working Level WL :

It is the concentration of any collection of short lived radon daughters in one liter of air which produces 1.3×10^5 MeV alpha particle energy . If the concentration of radon gas is 100 pCi/L of air , and it is in an equilibrium with its daughters , then it is said that the air is at one working level . The short lived radon daughters are : Po^{214} , Po^{218} , Bi^{214} , Pb^{214} and they are used in calculation of the WL . Table 1-3 shows the properties of these nuclei [4,7].

Table 1-3 : The Parameters Used In The Calculation of The WL [4,7]

Nucleus	α - energy MeV	Half – Life	No. of atoms/100pCi	Ultimate α energy/atom MeV	Total α energy MeV/100 pCi	Fraction of total α energy
Rn-222	5.49	3.82 day	1.77×10^6	Excluded	None	-
Po-218	6.0	3.05 min	977	6.0+7.68	0.134×10^5	0.1
Pb-214	0.0	26.8min	8580	7.68	0.659×10^5	0.52
Bi-214	0.0	19.7min	6310	7.68	0.485×10^5	0.38
Po-214	7.68	164×10^{-6} sec	0.0008	7.68	$\approx$ 0.0	0.0
					1.3×10^5	1

1-3 Radon and Its Daughters :

Radon gas exists everywhere in the environment surrounding us at different concentrations . There are three isotopes :

Rn^{219} which is a member of the U^{235} radioactive chain ,

Rn^{220} which is a member of the Th^{232} radioactive chain ,

Rn^{222} which is a member of the U^{238} radioactive chain ,

The properties of the second and the third isotopes are given in table 1-4 , 1-5 [5,7] and figures 1-1 , 1-2 [6] . The first isotope is very short lived (55.6 seconds), so there is not enough information about it . The third isotope is the most abundant. Small amounts of U^{238} can be found in some kinds of rocks and soils, but its major source is the inside of earth , so radon gas comes mainly from cracks in the terrestrial crusts and disperses into the houses and accumulates in badly ventilated rooms . In the case of bad ventilation , the atmospheric pressure inside the houses becomes less than that in the outside and hence the dispersion of radon into the houses through pores in the ground floor and the walls becomes higher .

Radon occupies an international attention because it is the source of most of the natural radiation that we encounter in our life . Many countries support projects for continuous radon monitoring and propose suitable suggestions.

Hazards From Radon and Its Daughters :

Radon is a gas , so it can be inhaled . It is chemically inert but it is a radioactive element and as mentioned above , it is a member of the U^{238} radioactive chain . The members of this chain are : Po^{218} , Pb^{214} , Bi^{214} , Po^{214} [49]. These elements are of solid form and they tend to attach themselves to solid particulates such as dust or vapor drops which can easily be inhaled and remain inside the body for a while . These elements decay by emitting α or β particles or γ radiation with different energies which can damage the live cells and cause different types of cancers . After inhalation of radon gas and its daughters, they distribute themselves uniformly through the whole body forming radioactive sources inside the body , specially the respiratory system . Solubility of radon gas in the body tissue is low , therefore , the effective dose equivalent from the inhalation of radon gas is small compared with that of the short lived radon daughters . The hazard from the longer lived elements is usually less because there is a possibility for them to be exhaled before they undergo any nuclear disintegration process [8,10] .

Table 1-4 : The Decay Properties of Rn^{220} and Its Daughters [7]

Nuclei	Half Life	Energy of The Main radiation & Its Percentage					
		α		β		γ	
		MeV	%	MeV	%	MeV	%
Rn – 220	55.6 sec	6.29	100	-	-	-	-
Po – 216	0.15 sec	6.78	100	-	-	-	-
Pb – 212	10.6 hrs	-	-	0.57 0.33	12 83	0.24 0.30	43 3
Bi – 212	60.6 min	6.09 6.05 -	10 26 -	2.25	64	1.62 0.79 0.73	18 11 7
Th – 208	3.1 min	-	-	1.8 1.5 1.3	51 22 23	2.6 0.58 0.51	100 86 22
Po - 212	0.3 μsec	8.78	100	-	-	-	-

Table 1-5 : The Decay Properties of Rn^{222} and Its Daughters [7]

Nuclei	Half Life	Energy of The Main radiation & Its Percentage					
		α		β		γ	
		MeV	%	MeV	%	MeV	%
Rn – 222	3.824 days	5.49	100	-	-	-	-
Po – 218	3.05 min	6.00	100	-	-	-	-
Pb – 214	26.8 min	-	-	1.02 0.70 0.65	6 42 48	0.35 0.30 0.24	37 19 8
Bi – 214	19.7 min	-	-	3.17 1.54 1.51	18 18 18	1.77 1.12 0.61	16 15 46
Po – 214	1.64×10^{-4} sec	7.69	100	-	-	-	-

Figure 1-1 : Decay Scheme for Th^{232} [6]

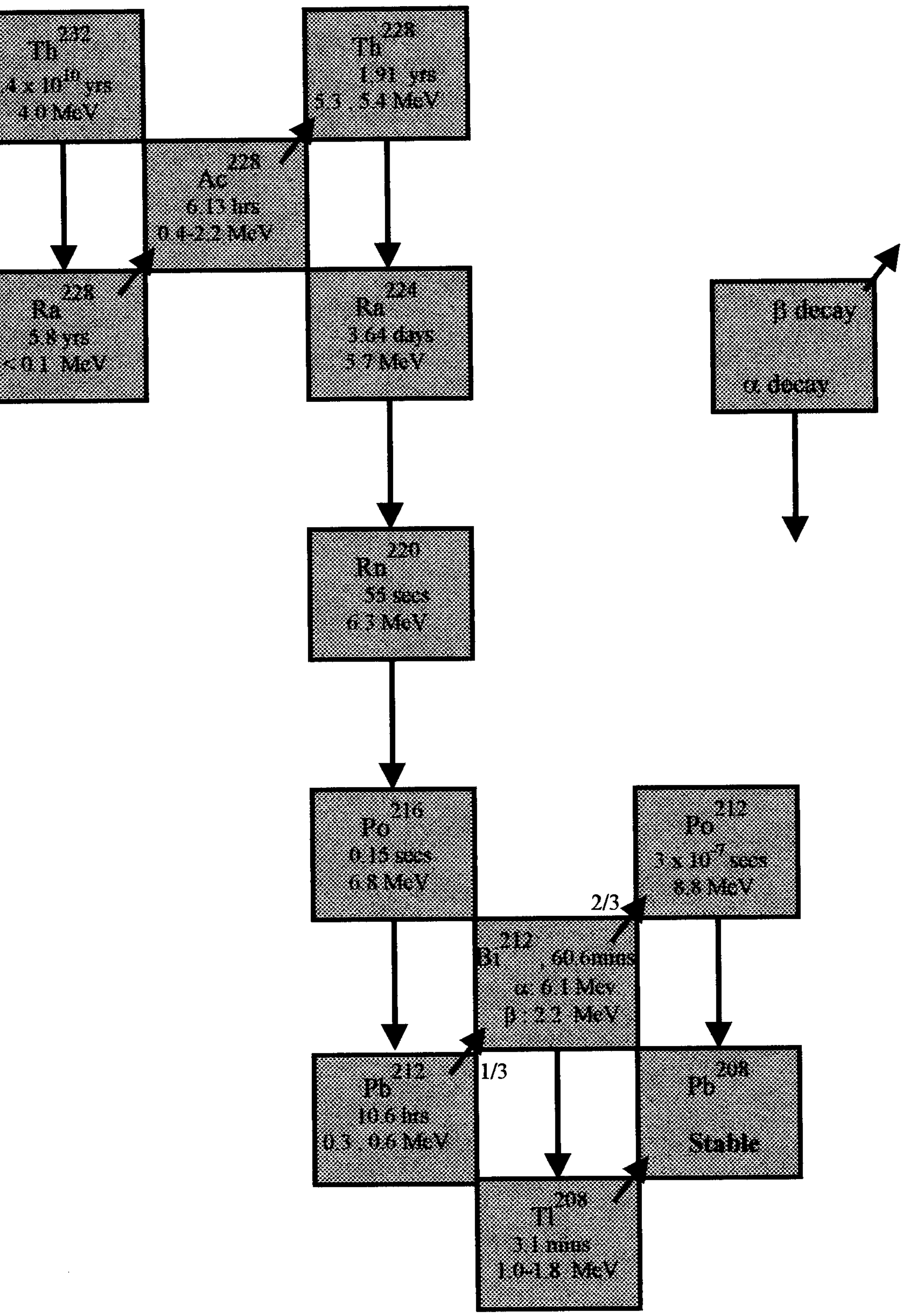
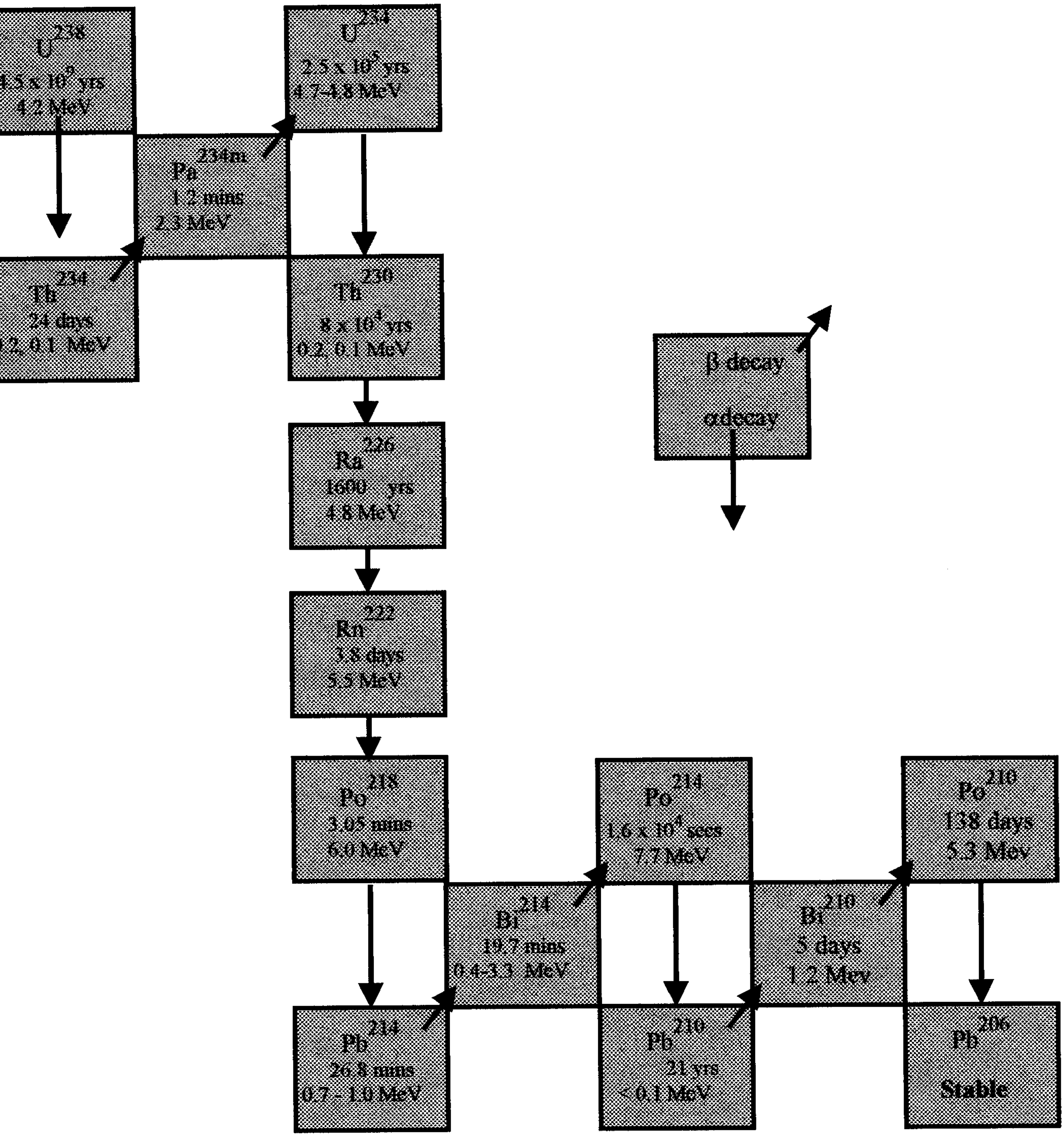


Figure 1-2 : Decay Scheme for U^{238} [6]



Methods of Radon and Radon Daughters Measurements :

There are several experimental methods for radon and its daughters measurements . Some of them are called the passive methods , such as :

1. Precipitating radon and its radioactive daughters atoms on a piece of charcoal to be left for few days in area where radon is to be measured , then analyzing this piece in the laboratory using suitable gamma or alpha spectroscopic system to determine the concentration of radon and its daughters .
2. Sucking some of the air of the area where radon measurement is required , through filter paper using rotary pump . The radioactive atoms of radon and its daughters are precipitated on the filter paper . These atoms are then detected and counted using suitable detection system .
3. Exposing certain type of plastic to the radon and radon daughter atoms in the required area for suitable period of time (30 days for example) . The emitted alpha particles form tracks in the plastic . These tracks can be made visible after being treated by suitable chemical reagents and then they are counted using an ordinary optical microscope . This type of plastic is known as : ***Solid State Nuclear Track Detectors (SSNTDs)*** . This method is used in the work presented in this thesis .

The active method :

4. This method depends on letting the radon gas passes through small chamber containing a small disc having negative electrostatic charge which attract the positively charged alpha particles emitted form radon gas causing a drop in the electrostatic potential . This drop is proportional to the radon concentration .

Radon Permissible limit :

The permissible limit for radon concentration inside houses according to the International Commission on Radiological Protection (ICRP) is 200-600 Bq/m^3. The Environmental Protection Agency (EPA) suggested 0.02 WL (which is equivalent to 2 pCi/L of Rn^{222}) as a maximum permissible limit [7 , 8] .

1-4 Gamma Radiation :

It is electromagnetic radiation and is generated in most of the nuclear decay processes . The main natural source for gamma radiation is the decay of K^{40} and the elements of the Th^{232} which are commonly present in the earth crust ,

so the gamma radiation level depends on the geographical location . Building materials such as concrete and bricks are usually manufactured from mud which is taken from the earth crust. These raw materials are the main source of gamma radiation inside the houses.

Methods of Gamma Measurements :

There are several methods for gamma radiation measurements in various locations of the environment , such as :

1. The use of battery operated Gieger – Muller as a detector in a survey meter , internally or externally fitted . They are calibrated to give direct equivalent dose rate reading .
2. The use of battery operated ionization chamber as a detector in a survey meter. They are calibrated on the base that 1 mrad/hr in air at normal pressure and temperature , gives rise to a current 1.06×10^{-16} ampere .
3. The use of ***Thermoluminescence Detectors TLD*** . They are special type of material when exposed to gamma or beta radiation and then heated to a suitable temperature , they emit light with intensity proportional to the radiation dose . Light intensity also depends on the detector material .

4. Spectroscopic systems consisting of NaI or Ge detectors with amplifiers, multi-channel analyzer and other relevant electronics . Some researchers managed to design portable spectroscopic systems and used them in the field.

Gamma Radiation Permissible Dose limit :

The international committees such as The International Commission of Radiation Protection (ICRP) defined the permissible doses equivalent [2] . They differentiated between the workers in the field of radiation and the rest of the public and they put different limits for both groups . The workers in the field of radiation are exposed to higher doses and they undergo continuous dose monitoring for safety purposes , while the rest of the public can be exposed to radiation randomly or and occasionally [60,61].

A – Dose Limits for Professional Workers :

1. The annual effective dose equivalent for professional workers is 20 mSv in such a way that the average of five consecutive years should not exceed 100 mSv and the annual dose should not exceed 50 mSv during this five years .
2. The annual effective dose equivalent for students and trainees is 6 mSv .

3. It is prohibited for youngers of age less than 16 years to reach the professional worker exposure limit to avoid affecting their biological growth.
4. The annual effective dose equivalent for the eyes is 150 mSv, and for the body extremities (hands and foots) and the skin is 500 mSv.
5. For pregnant ladies, the annual effective dose equivalent for the stomach and pelvis is 2 mSv, so that the fetus is exposed to less than 1 mSv during pregnancy period.

B - Limits for The public:

1. The annual effective dose equivalent for the public is 1 mSv in such a way that the average of five consecutive years should not exceed 5 mSv.
2. The annual effective dose equivalent for the eyes is 15 mSv , and for the body extremities (hands and feet) and the skin is 50 mSv .

1-5 cosmic radiation:

All types of radiation that reaches the earth coming from the outer space is called ***cosmic radiation***. It could be of galactic or solar origin and it consists of

Charged particles and heavy ions with very high kinetic energy. These particles interact with the atmosphere producing many different secondary radiations such as pi and mu-mesons, electrons, protons, neutrons, electromagnetic photons, with high energies reaching several hundreds of MeV. Some of these radiations have high penetrating power and reach the earth surface and some others interact with the components of the atmosphere in the different layers and lose substantial part of their energy and could be stopped there. The atmosphere is a good absorber for many types of cosmic radiation. Due to this filtration process, we expect the cosmic radiation to be less at the sea level than it is at the higher levels.

Cosmic radiation contains nuclei of special importance such as:

1. The radioactive C^{14} which is produced through the reaction N^{14} (n, p) C^{14}. It then diffuses to the lower atmosphere layers and interact with live cells. This element is a long-lived pure β-particles emitter with half life time ($T_{1/2}$) of 5568 years.

2. Small concentrations of : H^3 ($T_{1/2}$ = 13.36 year), Cl^{36} ($T_{1/2} = 3.08 \times 10^5$ year) and Ca^{41} ($T_{1/2} = 10^5$ year).

The method of cosmic ray measurement depends on the type of radiation . Several measurements were carried out in various parts of the world,such as : In 1989 the British Center for Radiation Protection estimated the annual equivalent dose due to the cosmic radiation in England to be 280 μSv . In 1993 the NCRP (National Center for Radiation Protection) estimated the annual equivalent dose due to cosmic radiation in the United States of America to be 270 μSv .

1-6 Other Radiation Sources :

There are several other radiation sources that participate in increasing the dose of the individuals in an environment , such as radiation doses used for medication . If radiation is used for diagnosis or treatment , these doses must be known and registered . In the industrial countries , radiation is used in many applications , for example :

1. **Research units :** usually use reactors , accelerators , high activity sources .
2. **Industrial applications** , such as power production , testing production lines , maintenance purposes .
3. **Agricultural establishments :** use gamma radiation for products sterilization and to speed up the growth of some kind of citrus fruits .

1-7 Aim of Present Study :

The aim of the study presented in this thesis is to determine radiation levels specially radon and radon daughter concentration in Makkah city , after performing physics study on the solid state nuclear track detector , CR-39 . All the related equipments are built in Umm Al-Qura University Physics Department workshops . An experimental survey study was performed to find the optimum conditions for the structure of the radon dosimeter and for the Electro-Chemical Etching process .

In addition , the dose equivalent due to gamma radiation in Makkah has been determined .

The importance of the present study can be summarized in the following :

1. Introducing values for radon and radon daughter concentration , gamma dose equivalent in various districts of Makkah . These values can be used as reference values in the case of any radiation accident , specially in the neighboring countries , to follow its effect on Makkah .
2. Makkah is a valley surrounded by mountains from all sides and the rocks of

these mountains could have different radioactive materials and there are many tunnels cut through these mountains . Besides that , Makkah receives millions of muslims every year from all parts of the world with different cultures . So it is very important to determine the radiation doses to which Makkah population are exposed . If these doses exceed the permissible limits , then suitable suggestions have to be made .

3. The continuous monitoring of radon gas emitted from the soil , helps in giving early warning about probable earthquakes specially in the districts where cracks in earth crust are known .

The thesis consists of four chapters . General introduction about the natural radioactivity and the most common methods for their measurement and the permissible limits , is given in the first chapter .

Literature survey about the previous published works in the field of radiation measurement, specially in Saudi Arabia , is given in second chapter.

The theoretical background is given in the third chapter . It included general description of radiation detectors , theories of operating mechanism

of the nuclear solid state track detectors (SSNTDs) and gamma survey meters , methods of concentration measurements and dose calculations .

The last chapter is devoted to display and discuss the experimental set up and obtained results . The experimental study was divided into two parts : the first part was completely done inside the laboratory to find the detection optimum conditions . The second part was concerned with the field study to determine the required radiation levels . This chapter was concluded with some suggestions and proposals for future studies .

Chapter Two
Literature Survey

2-1 Introduction :

There are some published works carried out about the natural radiation background in Saudi Arabia and in other parts of the world . These studies included radon gas and gamma measurements using different techniques, some of them are similar to the techniques used in this thesis . In this chapter, we present summaries of some of these papers .

2-2 Published Works In The field of Radon Measurements :

Recently, interest has grown up in collecting all possible information about natural radiation sources and determining the radiation dose to which human being are exposed in their local environments, specially that dose due to alpha particles emitted from the soil , building material , coal mines and industrial left behinds ... etc [10].

In 1983 , Somogyi and Zs. Varga [9] measured radon and radon daughter concentration inside the houses in Hungry . They used cups equipped with two nuclear track detectors and they presented theoretical treatments which many problems faced this type of measurements .

In 1984 , Abu-Jarad and Al-jar Allah [5] performed general study in houses of Saudi Arabia and measured radon and radon daughter concentration using CR-39 SSNTD . They fixed the detector inside properly sealed cans and left them inside the houses for seven months . Their study included : Damam , Khobar , Dhahran , Riyadh , Jeddah and Tayef . Their measurements showed that the radon concentration varies from 0.27 pCi/L in Khobar to 0.98 pCi/L in Tayef . In 1986 they repeated their study using the same technique [11] . They measured Radon concentration in 400 houses in Damam , Khobar , Khafji , Al-Jobail , Riyadh , Jeddah and Tayef . They found that radon concentration lies in the range 0.13 pCi/L - 0.43 pCi/L . They compared radon concentration in Saudi Arabia , which is a hot country , with the concentration in some European countries , which are cold countries . Although it is expected that hot weather should reduce the concentration , it is found that radon concentration in Saudi Arabia is not less than that in the cold countries . It was also found that the highest radon concentration in Saudi Arabia is in Tayef which is the coldest city, and that could be attributed to the presence of large amounts of phosphate, which contains considerable amounts of uranium , in the soil of Tayef .

Mamoon and Abdulfattah [12] measured radon concentration inside the houses in Jeddah in Saudi Arabia . They used charcoal to precipitate radon atoms and then they performed gamma spectroscopic study . Their study was carried out in 1989 and it showed that radon concentration in Jeddah is 2.2 pCi/L .

In 1991 , Tecson [51]. measured radon concentration in a tunnel underneath King Faisal Specialized Hospital in Riyadh . This tunnel interconnects most of the hospital buildings . Their study showed that the radon level is less than the permissible limits .

In 1993 , Khalid Al-Hassan [13] measured radon work levels inside and outside the houses in Riyadh city using active method . The results showed that the work level is 1.25 ± 0.2 m WL inside the houses and 1.1 ± 0.12 mWL outside the houses, which corresponds to an annual dose equivalent 0.41 ± 0.04 mSv .

In the industrial countries , mine workers are exposed to radon gas doses . These doses varies according to the location inside the mine . In 1986 , Bartlett et al. [14] developed radon dosimeter which can determine the exact dose to which the worker is exposed . They fixed SSNTD inside well sealed can . The can is then fixed on the clothes of the workers when they enter the mine . In an

another study , the same research team [15] studied the effect of humidity and some other parameters on this dosimeter .

In 1988 , Islam et al. [16] used CR-39 SSNTD to measure radon concentration due to building materials , inside the houses in Bangladesh . The study concentrated on houses having very thick walls built using mud . The study showed that radon concentration reaches values of 3.3 pCi/L which is ten times higher that the levels found in Saudi Arabia and in England . It also showed that the radon concentration in the rooms which are built using mud is higher than that in the rooms which are built using bricks .

In 1991 , Hafez et al. [17] determined Ra^{226} contents of the Egyptian soil using two types of SSNTD: CR-39 and LR-115. They put these detectors inside well sealed can equipped with dried sample of the soil . The sample was taken from the Delta area . They found that the Ra^{226} content was 25 ± 8 Bq/Kg . They also determined the porosity of this soil which was found to be 0.35 ± 0.03

In 1993 , Henshaw [18] wrote a survey article about the hazard of radon gas . He showed that if the dose exceeds the permissible limits , it could cause cancer in the worst cases . He also showed radon concentrations in several European countries , Japan and United State of America .

In 1994 , Hadler et al. [19] proved that CR-39 SSNTD can be used as an absolute radon and radon daughter dosimeter by using it as an alpha particle spectroscopic detector . Using this method , it was possible to determine the radioactivity of Rn^{222} and also they could distinguish alpha particles which are precipitated on the detector surface . They found that the calibration constant does not depend on the environmental conditions .

In England , Ball and Miles [20] collected all the available information about radon levels inside the houses in Kornwool and Devon and they related these information to geological information of the two cities . They found that the houses which are built on granite rocks (which contains uranium) have higher radon concentration . They noted that radon concentration emitted from the soil and the surface water is also high . The British authority regards these two cities to be of radon levels above the permissible limits .

Abu Al-Faraj et al. [21] carried out radon concentration measurements in Jeddah in Saudi Arabia using charcoal technique . The results of this study was not available for me .

2-3 Published Works In The field of γ-Radiation Measurements :

Gamma radiation forms an important part of the natural radiation background in any environment and several studies have been made in various parts of the world to determine the equivalent dose resulting from this type of radiation .

In 1982 , Martin [22] measured the annual radiation equivalent dose rate due to gamma radiation in Saudi Arabia . He found that it reaches the value 40.8 mrem/year inside the houses which are built using concrete and red bricks .

Owain and his research group [23,52] measured in 1986 the natural radiation background in some parts of Saudi Arabia using TLD detector . They performed spectroscopic study on the radioactivity of the soil . The results of their study were compared with the corresponding data in Taiwan and they found that the natural radiation background in Saudi Arabia was less than the background in Taiwan .

In 1987 , Al-Haj [24] performed gamma spectroscopic study on some soil samples in Riyadh .He estimated the annual dose equivalent to be approximately 0.57 mSv/year .

Khalid Al-Hassan and Nizar Wafa [25,26] measured in 1992 the natural radiation background inside the houses in twenty locations in Riyadh using TLD detectors . They fixed these detectors one meter above the ground . They recorded the reading every month for twelve months . They found that the average annual radiation dose equivalent is 0.6 mSv/year . The same research group [26] measured the natural radiation background outside the houses using TLDs in several cities . The average exposure rate was found to be 5.29 μR/hr in Dammam and 11.59 μR/hr in al-Khamees .

Al-Mohawes [27] measured , in 1984 , the natural radioactivity in some kinds of dates which are planted in some cities in Saudi Arabia . He found that the most common radioactive elements are : Sr^{90} , Cs^{137} , K^{40} and he found their activities to be : 1.84 , 47 , 18027 pCi/kg respectively .

In 1989 , Green et al . [28] measured gamma radiation absorbed dose rate outside the houses in Great Britain using dosimeter with an improved Gieger-Muller detector (energy compensated) called ***the mini – instrument*** . They found that the absorbed dose rate is 34 nGy/hr with an annual equivalent dose of 16μSv .

In 1990 , Gomma et al. [29] measured gamma radiation levels in some cities in the southern part of Saudi Arabia and in Makkah – Jeddah high way . They used portable spectroscopy system consisting of NaI detector , multi-channel analyzer and an amplifier . They detected the presence of K^{40} and the elements of the U^{238} and Th^{232} radioactive chains in the ground of Abha . The annual equivalent radiation dose is 116 μSv in Makkah – Jeddah high way and reaches the value of 508 μSv in the mountainous areas in Abha .

Chapter Three

Theoretical Background

3-1 Introduction :

The work presented in this thesis includes the following topics :

1. Natural radiation present in the environment and the parameters affecting them .
2. Nuclear detectors and associated electronics .
3. Methods of calculations .

In the first chapter of this thesis , we presented general summary about the natural radioactivity . It was mentioned that Makkah is a valley surrounded by mountains from all sides and the rocks of these mountains contain several radioisotopes . Some of these rocks are of granite type which contains uranium . The hot weather in Makkah makes the population largely depend on air conditioning which may lead to bad ventilation , hence increasing radon concentration .

This chapter will be dealing with the theories and operating mechanisms of the detectors used in the experimental measurements , specially the radon

detectors ; i.e. Solid State Nuclear Track Detectors (SSNTDs) . Methods of calculations and extracting values for the physical quantities under consideration are also presented .

3-2 Solid State Nuclear Track Detectors (SSNTDs) :

This type of detectors was first discovered more than 30 years ago , when Fleischer and his colleagues [30,53,54,55] introduced this technology in 1965 . It spread rapidly and has been used in many research and routine applications such as : heavy ions experiments , measurements done inside reactors and fission fragments recording , nuclear fusion experiments , space physics , geophysics , standardization , radiation and environmental protection [30] . This type of detector is a dielectric material , it could be organic such as polymers (plastic) or inorganic such as glass or mica or some types of crystals . From this point of view this type of detectors can be regarded as one of the earliest detectors (mica exists in the earth crust millions of years ago) and in the same time one of the most recent ones .The most popular and widely used types are :

CR-39 : It was discovered by Cartwright [31,50] . Its chemical formula is $C_{12}H_{18}O_7$ and its density is 1.32 gm/c.c. . It is sensitive to alpha particles

with energies up to 60 MeV , for protons and protons recoiled from neutrons with energies in the range 100 keV up to 10 MeV . This type was used in the work presented in this thesis .

LR-115 : Its chemical formula is $C_6H_8O_9N_2$ and it is sensitive to alpha particles with energies in the range of 0.1 up to 4 MeV [33] .

CN-85 : Its chemical formula is $C_{12}H_{14}O_{18}N_4$ and it is sensitive to alpha particles with energies in the range of 0.1 up to 8 MeV . The last two types are manufactured by Kodak [33,57] .

When an alpha particle reaches this detector , it starts colliding with the electrons along its path , depositing some of its energy to these electrons in each collision until it loses all its energy and stops . The positive ions resulting in the ionization processes , repulse with each other causing damage in the atomic structure along its path . This damage is called latent track and it registers the passage of the nuclear particle and some of its properties . When the detector is treated by a suitable etching chemical material , an acid or a base , the surface layers of the detector begin to corrode , the damaged areas corrodes quicker than rest of the surface . In this way the nuclear track becomes deeper and can be made visible by using suitable method such as optical microscope for example. When choosing the etching material ,

caution must be exercised not to choose materials in which the detector material can be dissolved .

SSNTDs exhibit many unique features such as [50]:

1. Relatively inexpensive .
2. Ease of use and development .
3. Permanence of recorded tracks .
4. Insensitive for moderately high background such as : β and γ radiation which are present in the uranium radioactive chains .

From the previous discussion , it can be concluded that the operation of this type of detectors can be divided into the following stages :

a. Track formation .

b. Chemical or electrochemical etching process .

c. Track counting

d. Calculation of the physics quantity under consideration .

3-2-1 Track Formation :

There is no single model which gives full description of track formation inside the detector material but several theories were proposed and they linked

the damage occurring in the atomic structure with the detector etchability. Some scientists [10,35,36,50,58] suggested relating track formation to some parameters such as : total energy loss , primary ionization produced by the nuclear particle , restricted energy loss etc in such a way that it is assumed that the track is formed if the value of the chosen parameter exceeds certain value , called ***critical value*** whatever the incident nuclear particle . In recent years , this theory was slightly modified and became acceptable to look for the parameter X, so that the linear flow of the chemical reagent along the track $V_T(X)$ remains constant for certain value for X [10,33] . In the following paragraphs we will give a summary for the most important track formation models which give theoretical predictions in good agreement with the experimental data .

I Total Energy Loss dE/dx :

It is one of the earliest models and most straight forward and it was proposed by Fleisher and his group [10,33] . It relates track formation to the energy that the incident particle loses in the unit length of its path in the detector material . It is assumed that the track is formed if the value of dE/dx exceeds some critical value [2] . This model was rejected by Fleisher himself when it failed to fit the experimental data of particles having higher energy . They replaced it by another

model based on the amount of primary ionization made by the incident particle itself .

II Primary Ionization :

This model relates track formation to the number of primary ionization events J made by the incident particle along its path . Based on the work done by Bethe [35] , J can be expressed as :

$$J = C' \, Z^2_{eff} / \beta^2 \, [\ln \, (\beta^2 / 1 - \beta^2) - \beta^2 - \delta + K] \qquad (3.1)$$

Where : Z_{eff} is the effective particle charge ,

β is particle velocity divided by light velocity c ,

C' and K are constants for each stopping medium ,

δ is a relativistic correction factor related to the polarizability of the stopping medium .

From eq. 3-1 , it can easily be seen that it is very difficult to calculate the absolute value of J , so it is used as a fitting factor , its value is obtained from finding the best fit of the theoretical prediction to the corresponding experimental data .The fitting process depends on the relation between J and β.This model proved to be successful in interpreting the experimental data taken for heavy ions and for high energy particles , and the critical value J_c was

extracted . In contrast with the previous model , the success of this model can be attributed to the fact that delta rays (secondary ionization events caused by the electrons emitted in primary ionization events when they gain sufficient energy) participate in the particle energy loss , but outside the track area ; i.e. they do not contribute to the track formation process . The dE/dx calculations take into account the energy loss caused by the delta rays whereas in the primary ionization model , the secondary ionization ; i.e. the delta rays ; is not taken into consideration , only primary ionization contributes to the calculations . Although this may not be completely true specially in the case of particles with very low energies , less than 1 MeV/nucleon, this drawback did not affect the success of this model [10,33].

III Restricted Energy Loss REL :

This model was suggested by Benton [36] to overcome the drawbacks of the first model . He excluded the energy lost by the delta radiation from the calculation of the energies used to form the track . This was done by cutting the energies used in the calculations in Eq (3-1) , at a certain value W_O in such a way that the energies lost by delta rays are not included . The restricted energy loss can be calculated using the following formula [10,33] :

$$(dE/dx)_{W<W_O} = (n_o e^4 / 8\pi \varepsilon_o^2 m_o c^2)(Z^2_{eff} / \beta^2)\left[\ln (W_{max} W_O / I^2) - \beta^2 - \delta - U\right] \quad (3.2)$$

where : W_{max} is the highest incident particle energy ,

W_O is a fitting parameter , which can be adjusted to obtain the best agreement between the theoretical predictions and the experimental data .

Fitting some available experimental data showed that W_O can take the values : 200 , 350 , 1000 eV . It also showed some similarity between this model and the Primary Ionization model and both of them show good agreement with the experimental data [10,33,56].

3-2-2 Chemical Etching (CE) :

The tracks made in the detector surface by the incident nuclear particles can be counted directly by an electron microscope . Electron microscope is an expensive equipment and is not always available in the research laboratory due to its high cost and complicated operation , therefore an alternative cheap method must be found . The alternative method is to enlarge the tracks using suitable chemical reagents to corrode the detector surface . When the tracks are enlarged , they can be seen by ordinary optical microscope . To follow the

chemical etching process , let us first assume that the track was formed perpendicular to the detector surface . When the detector is located inside the etching chemical reagent the damaged and the intact layers will be etched from both sides of the detector . Let us assume that V_B is the bulk etching velocity of the intact layers , and V_T is the track etching velocity of the damaged layers . V_B will be perpendicular to the detector surface and will be isotropic . It is called bulk etching rate [37] . V_T will be in the track direction and it depends on dE/dx of the incident particle and $V_T > V_B$. As a result , the track takes sharp ended conical shape as shown in figures 3-1 and 3-2 . As the etching time increases , the sharp ends become oblate . Figure 3-3 shows the track shape as a function of the etching time ; three different stages can be recognized . Etching time must be chosen carefully to maintain reasonable track shape [50].

V_B is given by :

$$V_B = h / t \quad (3\text{-}3)$$

$$V_T = L / t \quad (3\text{-}4)$$

where h is the thickness of the etched layer ,

L is the etched distance along the track ,

t is the etching time .

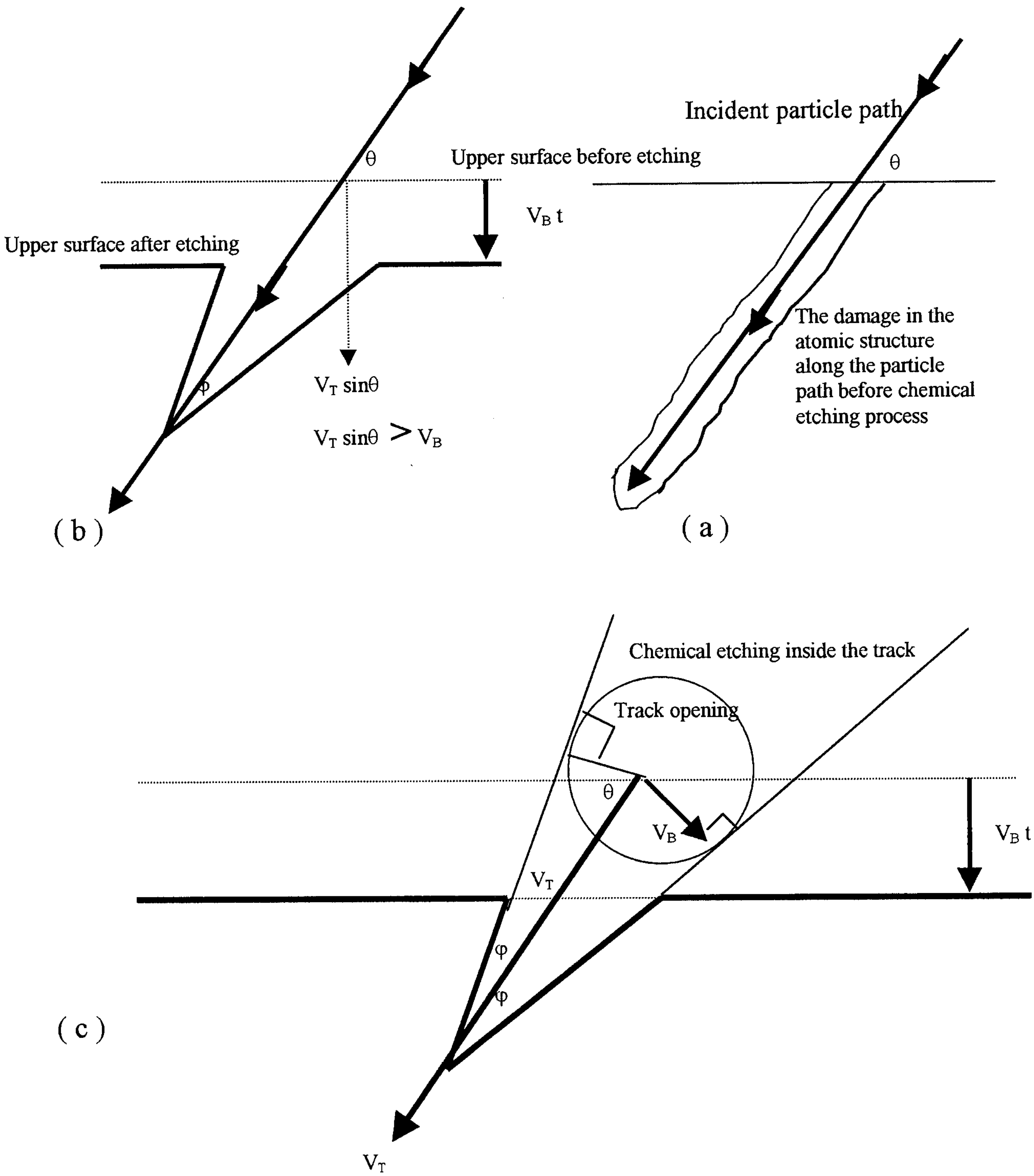


Figure 3-1 : Schematic diagram shows the shape of the track before and after chemical etching process . The track takes conical shape because $V_T > V_B$. The figure also shows incidence angle θ and the cone angle 2φ [37,50].

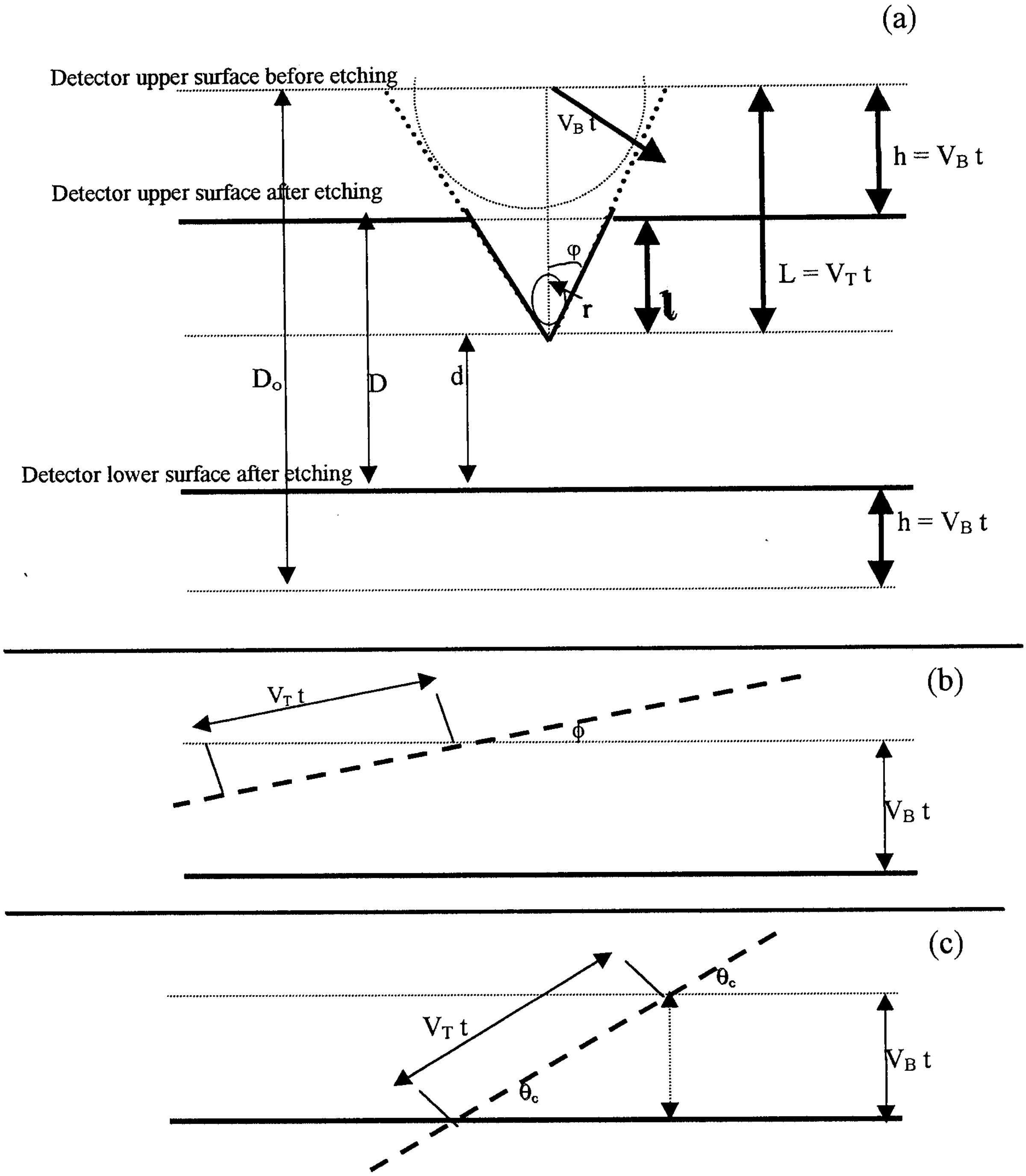


Figure 3-2 : (a) : Schematic diagram shows track chemical etching where intact layers are removed with velocity V_B less than the velocity V_T with which track layers are removed giving the track conical shape . D_o is the detector thickness before etching , D is the thickness after etching , d is the distance between the cone end and the lower detector surface , $\mathbf{l}$ is the distance between the cone end and the detector upper surface after etching , $\mathbf{l = D - d}$, r is the radius of the cone end . (b): nuclear track formed with an angle ϕ less than the critical angle, so it will disappear after etching because V_T is less than V_B . (c) : nuclear track formed with an angle greater than the critical angle , so it will be visible after etching [37,50] .

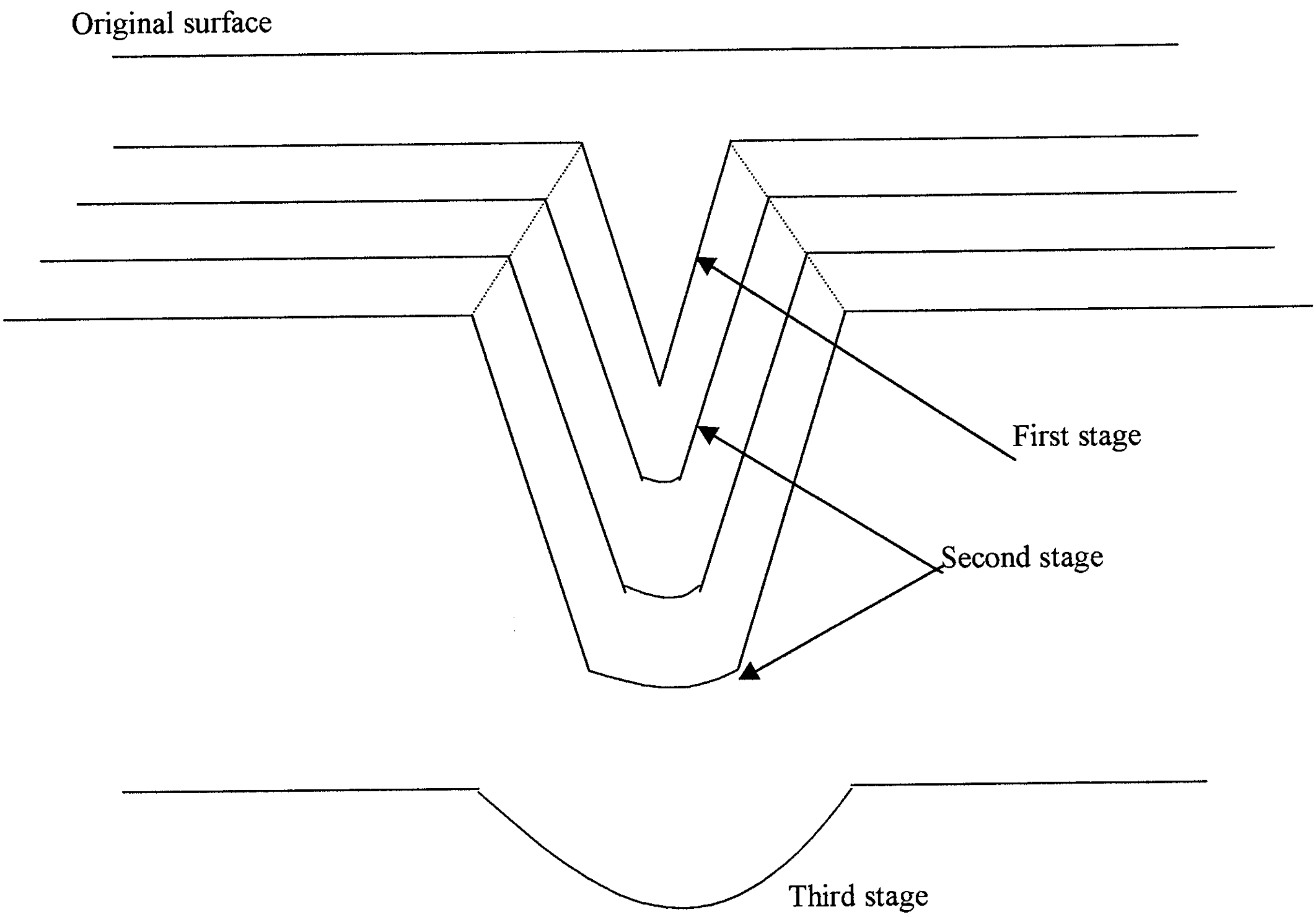


Figure 3-3 : The effect of etching time on the shape of the track
First stage : The track shape is conical sharp ended .
Second stage : The sharp end of the cone becomes oblate , where the damaged area etches with bulk etching rate V_B , as the intact areas .
Third stage : The damaged layers is now completely removed and the etching continue with V_B rate . The cone end becomes rounded [50] .

Although the chemical etching model described above does not take into consideration some fine details such as :

1. The possibility of having some changes in that etching rate due to possible depletion of the chemical reagent during etching process .
2. The possibility that the damage in the atomic structure is not homogenous along the particle path ,

It gives good description for all the observed aspects such as the complete disappearance of the tracks formed with small incidence angles . This means that the perpendicular component of V_T must be greater than V_B :

$$V_T \sin\theta > V_B$$

In other words , to avoid loosing the layers containing the tracks during etching process , the incidence angle must be greater than some critical value , θ_c which can be given by :

$$\sin\theta_c > h/L > V_B / V_T \qquad (3\text{-}5)$$

The critical angles for nuclear track registration in polymers lie in the range 5-15° . Some studies [36] showed that the detector sensitivity increases if oxygen is present during exposure period . On the other hand , the mechanism of track formation is improved by applying an electric field [50] .

Relative Etching Rate V [50]:

It is defined as the ratio :

$$V = V_T / V_B \quad (3\text{-}6)$$

It is a measure of the detector sensitivity and is related to the diameter of the track end D through the relation :

$$D = 2\,h\,\sqrt{(V-1)/(V+1)} \quad (3\text{-}7)$$

If $V >> 1$, then Eq. (3-7) becomes :

$$D = 2h \quad (3\text{-}8)$$

This condition is satisfied when the nuclear fission fragments reaches the detector perpendicular to the surface , so V_B can be calculated from the relation :

$$V_B = D/2\,t = h/t \quad (3\text{-}9)$$

If the condition $V >> 1$ is not satisfied , then V is given by :

$$V = (1+\gamma^2) / (1-\gamma^2) \quad (3\text{-}10)$$

where γ is defined as : $\gamma = D_* / D_{f.f.}$, the ratio between track end diameter for the nuclear particle D_* and for the fission fragments $D_{f.f.}$.

3-2-3 Electro Chemical Etching (ECE) :

It is a process in which the tracks are enlarged few hundreds of times , so that the tracks can easily be counted whatever small their number was . This is done

by exposing the tracks to the chemical etching reagent in the presence of high electric field . The detector is electrically isolated and the poles of electric potential are located inside the chemical reagent on both sides of the detector as shown in figure 3-4a . Since the chemical reagent is an electrical conductor and the electrical poles are located inside it , so it plays two important roles :

(1) the etching solution becomes electrical poles operating on both sides of the detector . It diffuses inside the detector layers , and the distance between the two poles is the detector thickness which is d in the track areas and D in the intact areas .

(2) etching the detector from both sides .

Electrochemical etching (ECE) processes were first applied on fission fragments and Tommasino [38] suggested in 1970 the application of this technique on alpha particles . Soharbi [62] used similar technique to enlarge neutron tracks in 1975. As mentioned before , in this technique high square or sinusoidal alternating voltage with suitable high frequency is applied across the detector in the presence of the etching solution at suitable temperature . In this way , the etching rate along the damaged areas highly increases in contrast with that of the intact areas . The tracks take the conical sharp ended shape much

quicker than what we would have using chemical etching process . The response of the various SSNTDs to ECE process differs from one type to another , the CR-39 detectors show the best response .

As time passes during the ECE process , the damage of the atomic structure increases and ramifies ; branching effect starts to appear at the cone end as shown in figure 3-3b .

The value of the electric potential at the cone end E_{tip} and the average value E_{avr} are given by Mason's equation [39,59] :

$$E_{tip} / E_{avr} = 2d / r \ln [1 + (4d / r)] \qquad (3\text{-}11)$$

$$E_{avr} = V / D$$

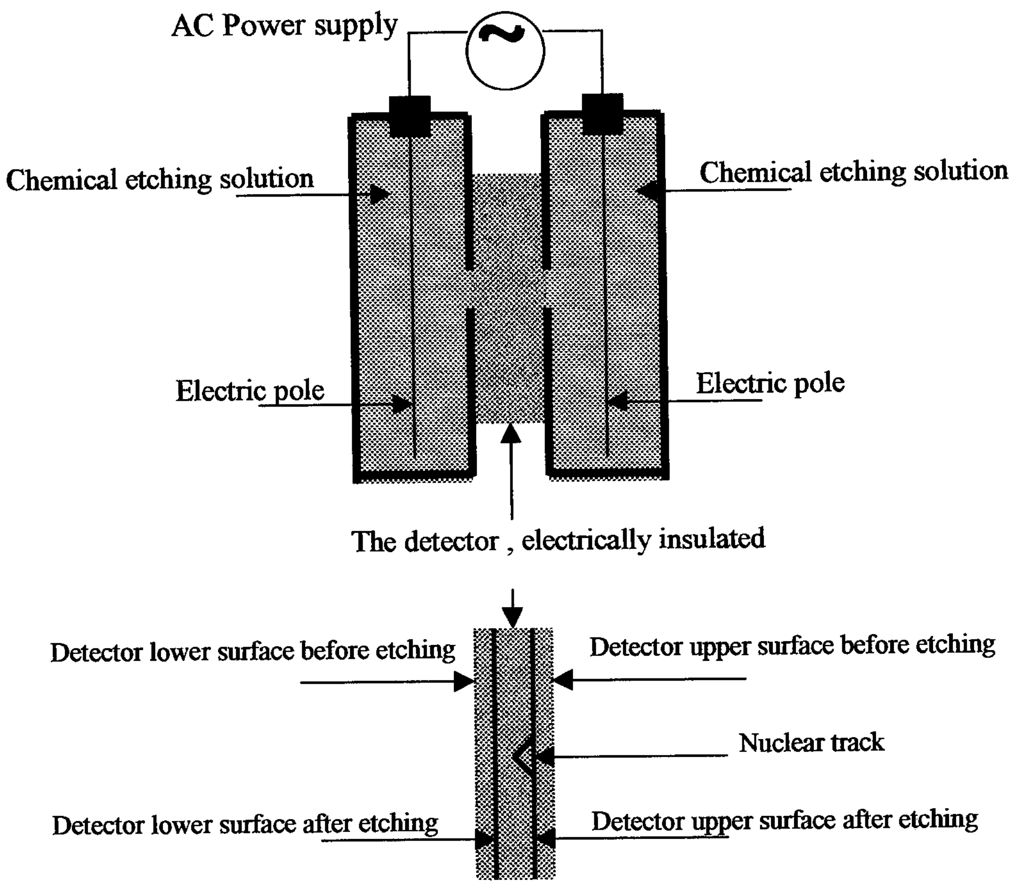
where D is the detector thickness ; the distance between the upper and lower detector surface after etching ,

r is the radius of the cone sharp end ,

E_{tip} is the electric potential at the cone sharp end ; it is the highest potential value ,

After ECE process , if the cone remains sharp ended ; i.e. its end did not become oblate and $r = 0$, then Mason's equation can not be applied . Al-Najjar et al. [40] modified this equation and suggested a formula that depends on the

(a)



(b)

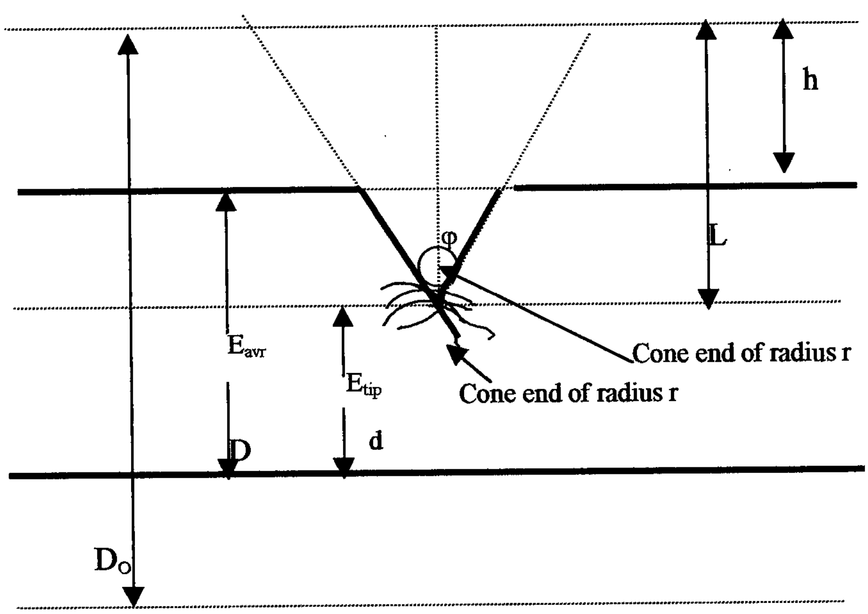


Figure 3-4 : (a) The electrical potential (b) Branching effect [40,50]

cone angle shown in fig.3-2a and fig.3-3a where we have :

$\varphi = \arcsin (V_B / V_T)$,

$l = D - d$ is cone length , which is the distance between the detector upper surface after etching and the cone end ,

$D = D_o - 2h$ is the detector thickness after etching ,

D_o is the detector thickness before etching ,

h is the thickness of the etched layer in the etching process from each side .

Several attempts have been made to find mathematical relations between the different parameters affecting the electric avalanche in the detector and to find the minimum potential value which can cause the avalanche , E_{crit} . The following formula has been proposed [40,63] :

$$E_{tip} = (E_{avr})\,(2d) / r \ln[1+(4d / r)] = (V/D)\,(2d) / r \ln[1 + (4d / r)] \qquad (3\text{-}12)$$

From figure 3-5 , we can find r in terms of φ :

$\sin\varphi = ON / OM = r / (r + r_O)$

where r_O is the distance between the tangent to lower rounded surface and the cone end , so we have :

$$r = r_O [\sin\varphi / (1 - \sin\varphi)] = r_O\, y \qquad (3\text{-}13)$$

$y = [\sin\varphi / (1 - \sin\varphi)]$

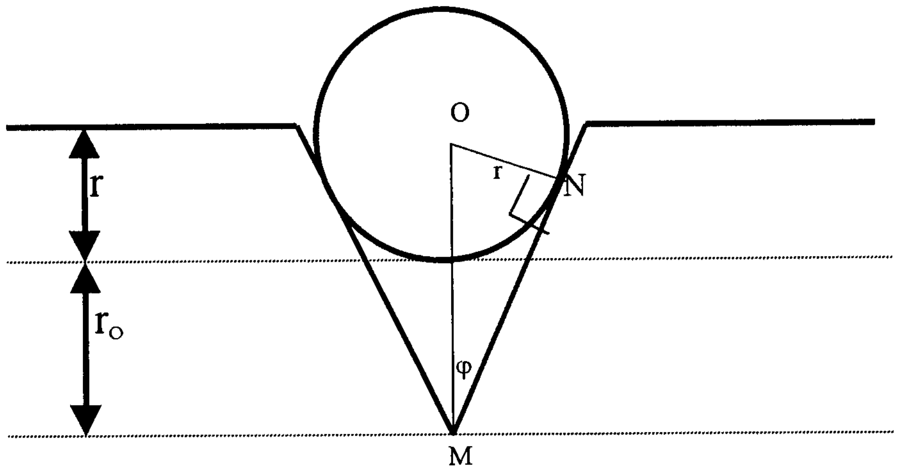


Figure 3-5 : Schematic diagram shows the relation between φ and r [46]

We notice that the as the value of φ becomes smaller , the value of r gets smaller as well . Al-Najjar and Durrani [40] proposed the following semi-empirical formula :

$r_{eff} = 0.43 + r_O . y$

Also , it was found that the value $r_O = 1.745\mu m$ gives complete solution for Mason's equation for the ECE for alpha particles [40,63] .

3-3 Radon and Radon Daughters Concentration Calculations :

Alpha particles are emitted in the decay process of radon gas and its daughters and then they are registered by the SSNTDs . The alpha particles tracks formed on the detectors are counted using an ordinary optical microscope and the number of tracks per unit area is called the ***Track Density*** , from which radon gas activity concentration is calculated in the following way :

A small piece of the detector material (about 2cm × 2cm) is fitted inside a can as shown in figure 3-6 , the can is then covered using polyethylene "P_e" piercing cover . The can is left for sufficient period of time in the location where radon is to be measured . It is well known that if a decay process occurred in the atmospheric air and produced some radioactive nuclei of solid elements , these elements tend to attach themselves to water vapor or dust particulate present in the air . The P_e piercing cover fixed on the can opening prevent such particulate from entering the can allowing only radon gas to enter . After a suitable period of time the atmospheric air in that location and the air confined in the can reaches uniformity and equilibrium stage .

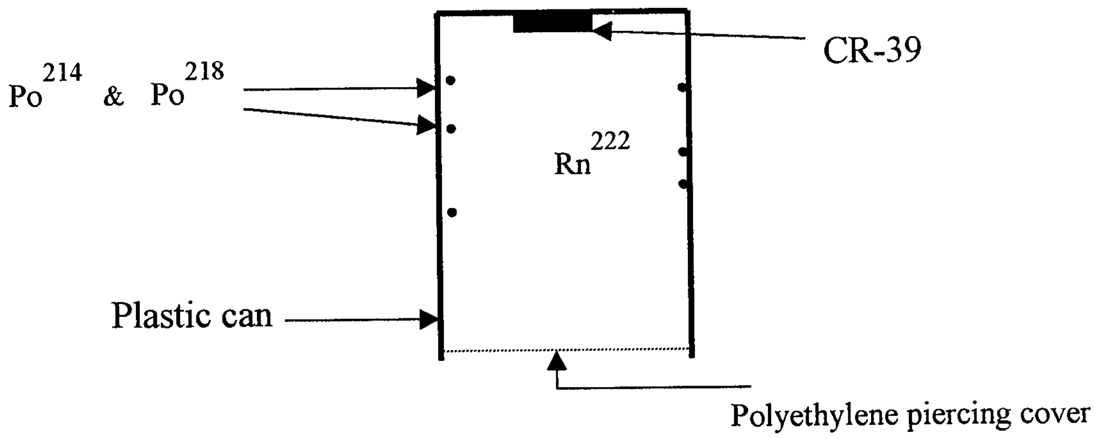


Figure 3-6 : Schematic diagram for the detection system

We will confine our discussion to Rn^{222} which is a member of the U^{238} radioactive chain , as was shown in fig.1-2 . If we apply the ***General Law of Radioactivity*** on this chain assuming that , at a particular moment , only Ra^{226} atoms are present , with the decay constants as follows :

$\lambda_{Ra} = 1.35 \times 10^{-11}\ sec^{-1}$, $\lambda_{Rn} = 2.1 \times 10^{-6}\ sec^{-1}$.

Any radioactive chain is said to be in an equilibrium if the rate of decay of any element is equal to the rate of the formation of the next element in the chain . This can mathematically be expressed by letting the first derivative of the function with respect to the time equal to zero [41] . If the radon radio-activity per unit volume is denoted by C_{Rn} , and the radium activity per unit volume is denoted by C_{Ra} , then $C_{Rn} = \lambda_{Rn} N_{Rn}$, $C_{Ra} = \lambda_{Ra} N_{Ra}$, where N is the number of atoms per unit volume and the decay rate is :

$$d\,N_{Ra} / dt = -\lambda_{Ra}\, N_{Ra} \tag{3-14}$$

Due to the decay of radium atoms , radon atoms are formed with rate equal to $\lambda_{Ra}\, N_{Ra}$ and they decay with decay rate equal to $\lambda_{Rn}\, N_{Rn}$, so we have :

$$d\,N_{Rn}/ dt = \lambda_{Ra}\, N_{Ra} - \lambda_{Rn}\, N_{Rn} \tag{3-15}$$

If the chain is in radioactive equilibrium , then from Eq. 3-14 ,we find that :

$$-\lambda_{Ra}\, N_{Ra} = 0 \quad ,$$

and since we assumed at the beginning that only Ra^{226} atoms are present , this means that λ_{Ra} must be very small in contrast with the other elements decay constants for the chain to be in radioactive equilibrium . From Eq.3-15, we have:

$$\lambda_{Ra}\, N_{Ra} = \lambda_{Rn}\, N_{Rn} \tag{3-16}$$

By integrating Eq.3-15 , we have [45] :

$$N_{Rn} = [\, \lambda_{Ra} / (\lambda_{Rn} - \lambda_{Ra})\,]\, N_{Ra}^{\bullet} (e^{-\lambda_{Ra} t} - e^{-\lambda_{Rn} t}) \tag{3.17}$$

Assuming that λ_{Ra} is very small i.e. $\lambda_{Ra} \approx 0$, so $e^{-\lambda_{Ra} t} \approx 1$ and also

$$\lambda_{Rn} - \lambda_{Ra} \approx \lambda_{Rn} ,$$

Substituting from Eq.3-17 in Eq. 3-16 we get ,

$$N_{Rn} \cong (\lambda_{Ra} / \lambda_{Rn})\, N_{Ra}^{\bullet} (1 - e^{-\lambda_{Rn} t})$$

$$\lambda_{Rn}\, N_{Rn} \cong \lambda_{Ra}\, N_{Ra}^{\bullet} (1 - e^{-\lambda_{Rn} t})$$

$$C_{Rn} \cong \lambda_{Ra}\, N_{Ra}^{\bullet} (1 - e^{-\lambda_{Rn} t})$$

$$C_{Rn} \cong C_{Ra}^{\bullet} (1 - e^{-\lambda_{Rn} t}) \qquad (3\text{-}18)$$

$$C_{Ra} \cong C_{Rn} / (1 - e^{\lambda_{Rn} . t}) \qquad (3\text{-}19)$$

The detector receives alpha particles emitted from :

Rn^{222} (its energy is 5.49 MeV and its range in air is 4.08 cm) and

Po^{218} (its energy is 6.0 MeV and its range in air is 4.67 cm) and

Po^{214} (its energy is 7.7 MeV and its range in air is 6.91 cm) ,

the elements Pb^{214} ، Bi^{214} ، Pb^{210} are members of the radioactive chain but they are beta particle emitter which can not be registered by the SSNTD used in this study . The sensitivity of the detection system K depends on the range of these particles . Since radon is a gas , so we will assume that it is the only element present in the air confined in the can , the two polonium isotopes will attach themselves to the can walls .

The Relation Between Track Density and Radon Gas Concentration :

The detector is fitted on the bottom of the can . Let a be the can radius , h is the can height and R is the alpha particle range , so that $0 < a < R$. Let us consider volume element dV of the air inside the can , it contains radon gas

atoms only . Let $\Delta\rho$ be the track density registered on the detector in unit time resulting from the volume element dV . From figure3-6 , we have :

$$\Delta\rho = \left(C / 4\pi r^2\right) \sin\theta \ dV \ dt \qquad (3.20)$$

Integrating both sides , we get :

$$\rho = \left[2\pi \int_0^{a/\cos\theta_c} \int_{\theta_C}^{\pi/2} (C / 4\pi r^2)(\sin\theta \cos\theta \, r^2 \, d\theta \, dr) + 2\pi \int_0^{R} \int_{\theta_R}^{\pi/2} (C / 4\pi r^2)(\sin\theta \ \mathrm{Cos}\theta \, r^2 \, d\theta \, dr)\right] \int_0^{T} dt$$

$$= \left[(C/2) \int_0^{a/\cos\theta_c} \int_{\theta_C}^{\pi/2} \sin\theta \ \mathrm{Cos}\theta \ d\theta \ \ dr + (C/2) \int_0^{R} \int_{\theta_R}^{\pi/2} \sin\theta \ \mathrm{Cos}\theta \ d\theta \ \ dr \right] T$$

$$= \left[(C/2) \int_0^{a/\cos\theta_c} \left[1/2 \sin^2\theta \right]_{\theta c}^{\pi/2} dr + (C/2) \int_0^{R} \left[1/2 \sin^2\theta \right]_{\theta R}^{\pi/2} dr \right] T$$

$$= \left[(C/4) \int_0^{a/\cos\theta_c} \left[1 - \sin^2\theta_c \right] dr + (C/4) \int_0^{R} \left[1 - \sin^2\theta_R \right] dr \right] T$$

From fig. 3-6 , $\cos^2\theta = (a^2 / R^2)$

$$= \left[(C/4) \cos^2\theta_c \int_0^{a/\cos\theta_c} dr + (C/4) \int_0^{R} (a^2 / R^2) \ dr \ \right] T$$

$$= \left[(C/4) \cos^2\theta_c \left[\ r \ \right]_0^{a/\cos\theta_c} + (C/4) \ (a^2) \left[-R^{-1} \right]_{a/\cos\theta c}^{R} \right] T$$

$$= \left[(C/4) \cos^2\theta_c \left(a / \cos\theta_c \right) + (C/4) (a^2) \ [-R^{-1} + \cos\theta_c / a] \right] T$$

$$= \left[(C/4) \, a \cos\theta_c + (C/4) (a) \left[\cos\theta_c - a / R \right] \right] T$$

$$= C \, (a / 4) \, (2 \cos\theta_c - a / R) \, T$$

$$\rho = C\ (a/4)\,(2\cos\theta_c - a/R)\,T \tag{3-21}$$

This equation can take the form :

$$\rho = C\,K\,T \tag{3-22}$$

where the constant K can be given by :

$$K = a/4\,(2\cos\theta_c - a/R) \tag{3-23}$$

ρ represents the track density resulting from all alpha particles which are present inside the can , and as mentioned before there are two sources for these alpha particles [19] :

1. ρ_1 results from the decay of radon atoms present in the air confined inside the can and from the decay of its resultant daughters .
2. ρ_2 results from radon daughters which enters the can, without their radon parent atoms, and attach themselves to the detector surface or can walls .

   $\rho = \rho_1 + \rho_2$.

Since the can is covered with a plastic cover , so the detection system is isolated against the second type ; ρ_2 , and radon atoms are in equilibrium with their daughters , so the number of each daughter is equal to the number of radon atoms . Equation 3-21 is then can be written as :

$$\rho = C_{Rn}\ (a / 4) \left[\Sigma_i \left(2 \cos\theta_c - a / R_i \right) \right] T \tag{3-24}$$

$$\rho = C_{Rn}\ (a / 4) \left[(2 \cos\theta_c - a / R_{Rn}) + (2 \cos\theta_c - a / R_{Po\text{-}214}) + (2 \cos\theta_c - a / R_{Po\text{-}218})\right] T \tag{3-25}$$

To estimate the hazard of radon , the equivalent dose due to the inhalation of short lived radon daughters can be calculated using the working level WL defined in the first chapter of this thesis , in the following way [3 , 7] :

$$WL = 0.01 \times F \times \text{radon concentration in pCi/L} \tag{3-26}$$

The absorbed dose D :

$$D = WL \times E_{WL} \times A \times 365 \times 1.6 \times 10^{-13}\ \text{Joul / year} \tag{3-27}$$

$$H = D \times QF \tag{3-28a}$$

$$H_E = H \times w_T \tag{3-28b}$$

F is an Equilibrium factor which expresses the decrease in the short lived radon daughters present actually in the air , compared with what should be in secular radioactive equilibrium state . Its value lies in the range 0.1 – 0.8 [4] , w_T is the weighting factor and its value for the lung is 0.12 .

E_{WL} is the total alpha particle energy available in 1 WL , see table 1-3 :

$E_{WL} = 1.3 \times 10^5$ MeV / L

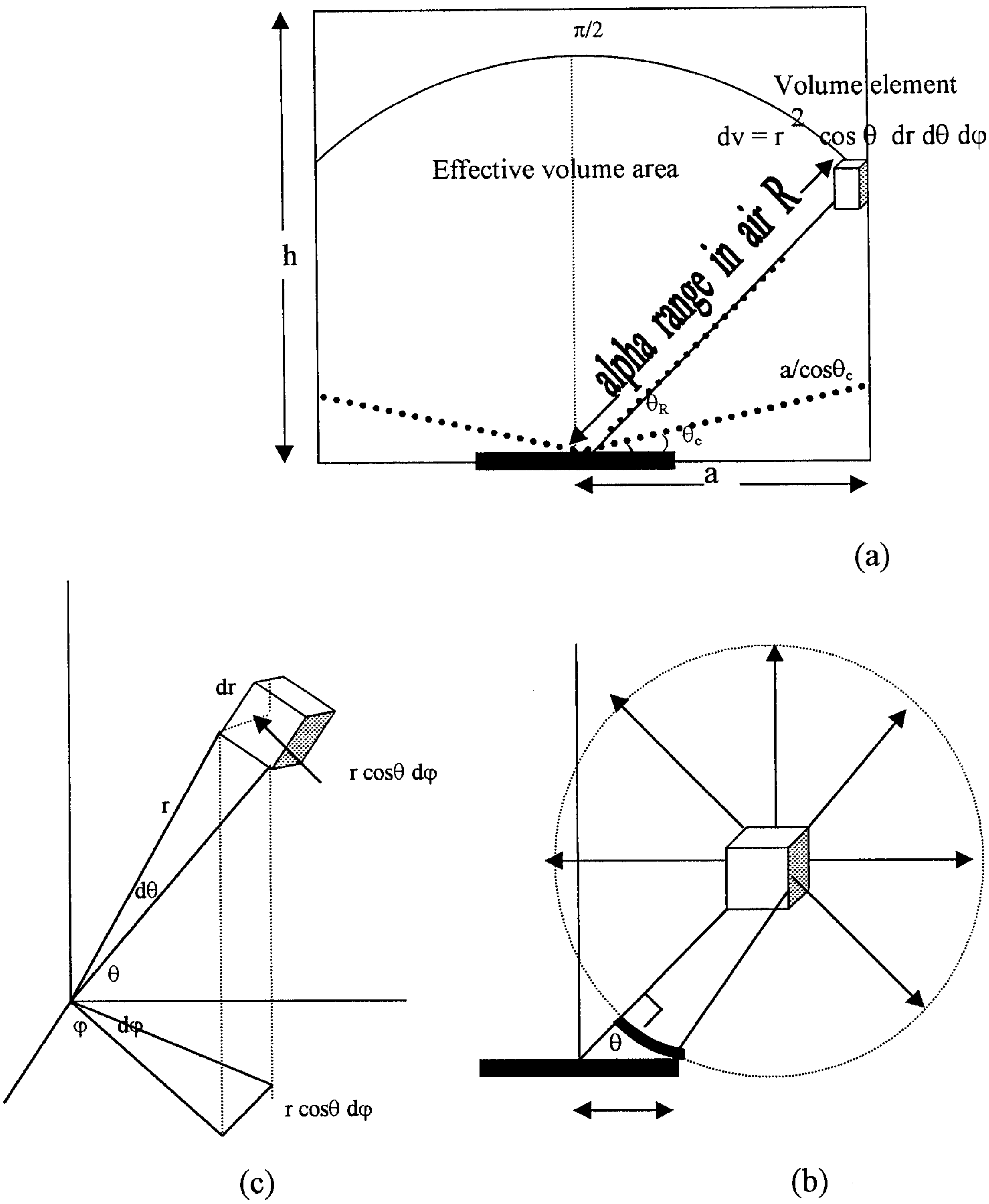


Figure 3-6 : Schematic diagram shows the geometry used in radon concentration calculation from track density . (a) shows that the angle of incidence takes the value θ_c to $\pi/2$. (b) shows that radon atoms in the volume element dV emits alphas isotropically in a sphere with surface area $4\pi r^2$. (c) shows the volume element .

A is the total indoor daily volume of air inhaled by an adult, its value is estimated to be [3] :

Table 3.1 : The average breathing rate per day for adults

Place	Activity	Part of day hr	Average Inhalation rate L/min	A
Indoor	Light	12	$(28 + 17)/2 = 22.5$	16200
	Sleeping	7	$(7.2 + 4.8)/2 = 6$	2520
				18720
Outdoor	Light	5	$(28 + 17)/2 = 22.5$	6750

QF is the quality factor given in table 1-1 and its value for alpha particles is QF=20

U^{238} activity concentration C_U in the rocks and rocks content of uranium can be determined using nuclear track detector to record the emitted alpha particles tracks . A sample of the rocks is polished and a piece of the detector material is located underneath the sample as shown in figure 3-7 , and left for a period of time T . Total track density ρ_{tot} is determined . U^{238} radioactive chain is usually present together with the Th^{232} chain and the ratio between . Th^{232} and U^{238} is 4:1 . The rocks content of uranium can be determined by following a procedure similar to that used to determine radon activity concentration in air , we have [17,42,43] :

$$\rho_U = C_U \; K_U \; T \qquad (3\text{-}29)$$

$$\rho_{Th} = C_{Th} \; K_{Th} \; T \qquad (3\text{-}30)$$

$$\rho_{total} = \rho_U + \rho_{Th} \qquad (3\text{-}31)$$

$$\rho_{tot} = C_U \; K_U \; T + C_{Th} \; K_{Th} \; T \qquad (3\text{-}32)$$

$$\rho_{tot} / T = C_U \; K_U \; + C_{Th} \; K_{Th} \tag{3-33}$$

$$= C_U \; K_U \left[1 + (C_{Th} / C_U)(K_{Th} / K_U) \right] \tag{3-34}$$

The ratio $C_{Th} / C_U = 4 : 1$,

$$\rho_{tot} / T = C_U \; K_U \left[1 + 4 (K_{Th} / K_U) \right] \tag{3-35}$$

$$K_U = 0.25 \; A_U \; \cos^2 \theta_c \; \sigma \; \sum_i R_i \, e_i \tag{3-36}$$

K_{Th} is given by a formula similar to 3-36 .

σ is the rock density , R_i is the alpha particle range for each element in the series with an energy E_i . A_U the radioactivity concentration of 1 ppm (one **part per million**) uranium . The values of these constants are given in table 3-2 .

Ra^{226} activity concentration C_{Ra} in the soil and soil content of radium can be determined using nuclear track detector to record the emitted alpha particles tracks . A sample of the soil is located `in a cylindrical container together with a piece of the detector material as shown in figure 3-8 , and left for a period of time T . The track density is given by [17] , [42] :

$$\rho = C_{Ra} \; K_{soil} \; T \tag{3-37}$$

K_{soil} is a constant that depends on the soil density , porosity , total emanation factor and the length h . Similar measurements carried out on the Egyptian soil [17] , [43] showed that the value of this constant is :

$K_{soil} = 0.49$ tracks . kg / cm^2 . Bq . day

and the radioactivity concentration of 1 ppm (one part per million) radium is given by [43] : $A_{Ra} = 0.0127$ Bq / gm

These values were adopted in the present **feasibility study**. However , thorough and detailed investigation has to be carried out in order to obtain more appropriate results .

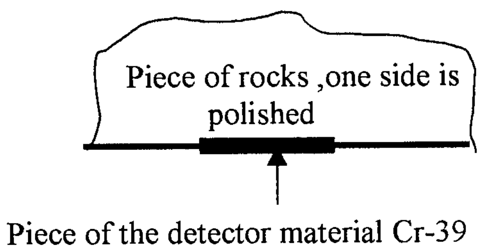


Figure 3-7 : Schematic diagram showing the equipments used for measurements of uranium contents in the rocks .

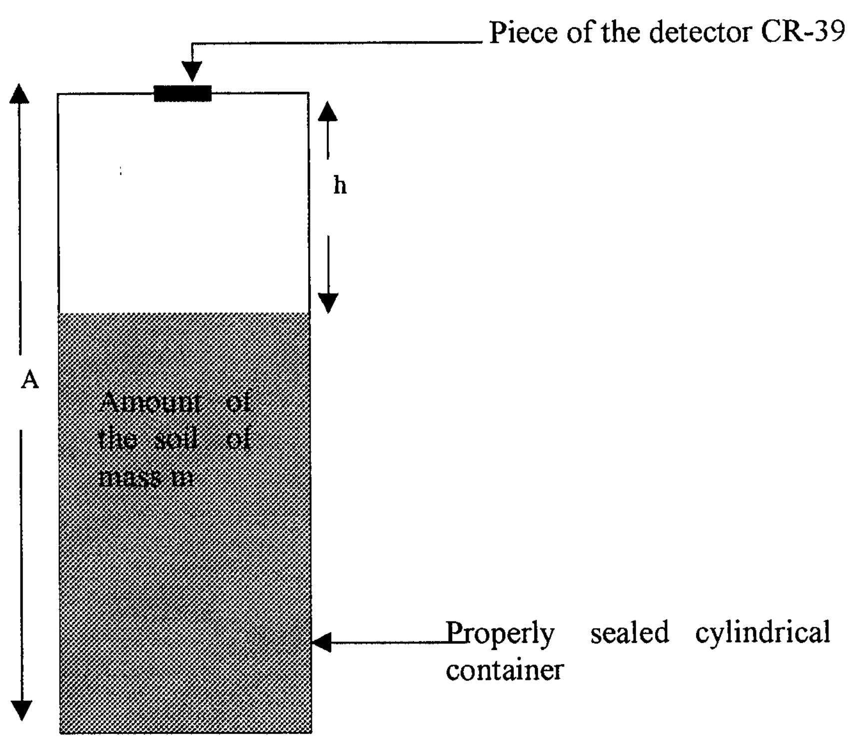


Figure 3-8 : Schematic diagram showing the equipments used for measurements of radium contents in the soil [17] .

Table 3-2 :The values of the constants used for the calculation of K_U and K_{Th} [17, 44]

U^{238}				Th^{232}			
Isotope	E_i MeV	R_i 10^{-4} cm	e_i	Isotope	E_i MeV	R_i 10^{-4} cm	e_i
U^{238}	4.19	15.87	1	Th^{232}	4.01	14.86	1
U^{234}	4.77	19.27	1	Th^{228}	5.42	23.34	1
Th^{230}	4.62	18.37	1	Ra^{224}	5.71	25.24	1
Ra^{226}	4.78	19.33	1	Rn^{220}	6.30	27.50	0.36
Rn^{222}	5.49	23.8	1	Po^{216}	6.8	29.18	1
Po^{218}	6.0	27.19	1	Bi^{212}	6.78	32.66	1
Po^{214}	7.68	39.37	1	Po^{212}	8.78	48.125	0.64
Po^{210}	5.3	22.57	1	–	–	–	–
$A_U = 0.0123$ Bq / gm				$A_{Th} = 0.0041$ Bq / gm			

3-4 Gamma Radiation Detection :

The equivalent radiation dose due to gamma radiation was measured using survey meters that use Geiger-Muller detectors . They are calibrated to give direct dose reading in sievert Sv units . Geiger counters are well-known detectors and the theories of their operation are given in many books [45] .

Chapter Four

Experimental Measurements and Results

4-1 Introduction :

In this chapter , we present the experimental methods and the set up used to perform the study reported in this thesis . The results and experimental data are then given and discussed .

Radon study included an experimental investigation to find the optimum values for the parameters involved in the measurements , such as the parameters affecting :

(1) the construction of the detection system ; i.e. the can height and radius , and

(2) the ECE process ; i.e. the high voltage , frequency and etching time .

An experimental study was then carried out to determine the critical angle of the detector material , CR-39 . Having experimentally revealed the optimum values for the parameters involved in the measurements , sufficient number of the detection system were prepared and then distributed in various districts of Makkah . They were left for 30 days and then collected and analyzed . Radon concentration was then extracted from the collected data .

Gamma radiation measurements were done using a survey meter with battery operated Geiger-Muller built in detector which is calibrated by Nuclear Enterprise to give direct equivalent radiation dose in Sievert (Sv) units .

4-2 Radon Gas Measurements :

Tracks formed by alpha particles emitted from radon and radon daughter nuclei are recorded in the CR-39 SSNTD . These tracks are made visible through ECE process . An optical microscope with a screen connected to it is then accurately used to count these tracks. The use of the screen highly improves the counting accuracy and makes it less tedious. As mentioned in the previous paragraph , there are several parameters that affect the performance and accuracy of the can – technique . Some of these parameters affect the ECE process such as the design of the etching cell , the applied voltage , frequency and etching time . Some other parameters affect the geometry of the can such as its height and radius . The detector critical angle must be determined accurately . If these parameters are not optimized , the branching effect increases , or the shape of the tracks might be distorted or their diameters become very large , so they can be overlapped . To perform parameter optimization study , sufficient number of pieces cut from the detector material (CR-39) with dimensions 2cm $\times$ 2 cm , are irradiated in an identical way using Am^{241} radioactive source and

they were used to find the best values for the voltage V , the frequency F and the etching time t . The best height and radius for the can are determined by preparing suitable number of groups of cans ; some of them had the same height but different radius , and some other group had the same radii but different heights . All these groups were located in one area in order to expose them to the same radon concentration .

4-2-1 Equipments and Instruments :

For radon and radon daughter measurements , the following devices and equipments were used :

I Determination of Optimum Values For ECE Parameters :

For this purpose , the following devices and equipments were built in the Faculty of Applied Sciences Physics Department workshops :

1. ECE cell ,
2. Irradiation unit ,
3. Alternating high voltage power supply with variable high frequency .

II Critical Angle Determination Set up .

III Determination of Optimum Values for Can-Technique parameters .

1. ECE cell :

Figure 4-1 shows a cross section of the ECE cell which was used in the present work . It was built by the Physics Department workshop . It is a single detector cell and a glance about it was given in chapter 3 , fig.3-4a . It is made up from high density polyethylene and it contains vertical grove to insert the chemical solution (Na OH) and another horizontal grove of radius 1.5 cm to keep the chemical solution (Na OH) and to locate one electrode inside it , the whole solution becomes conductive electrode .No corrosion is made by this solution . The electrodes are made of platinum or silver or stainless steel to avoid interaction with the chemical used . The SSNTD is fitted on the opening of the horizontal grove . To prevent leakage and to obtain high insulation , a silicon rubber ring , 1 mm thick , is fixed around the horizontal grove opening inside a shallow surface grove and the detector is located on this ring with the side containing the tracks directed to the outside of the cell . A stainless steel ring is used to fix the detector using four bolts . The cell is then located inside a beaker containing the same chemical solution (Na OH) with different concentration , and the other electrode is located inside the beaker . The beaker and its contents is then covered by a plastic disc and kept at 70^{o} C using water path

fitted with a thermostat . The high voltage is then applied and the sinusoidal shape and the frequency of the electrical signal are monitored by an oscilloscope during the whole period of each experiment .The chemical etching solution is Na OH used with two different concentrations:6.25N in the beaker and 0.1N in the horizontal grove of the cell .

2. Irradiation Unit :

To carry out all the required parameter optimization experiments and to determine the critical angle of the detector material , it was very essential to have sufficient number of identical pieces of the detector material ; i.e. having exactly the same number of tracks , in order to find out the effect of the parameters under consideration . To do that an irradiation unit was designed . It is shown in fig.4-3 and consists of a holder for the Am^{241} located behind a very thick lead absorber having a small hole in its center so that the source can be regarded as a point source which gives a collimated beam . The hole can be automatically opened and closed for the required period of time using a photocell derived by a digital clock . The detector piece is located parallel to the lead barrier in front of it , so that the

angle of incidence is 90° . All this set up is located inside a chamber connected to a rotary pump , so that the pressure inside the chamber is 10^{-4} bar , to reduce collision with air atoms and to ensure identical irradiation .

3. High Voltage Power Supply :

This unit was built by the physics department electronic workshop technicians. It give sinusoidal alternating voltage in the range 0 – 6000 volts . The frequency can be varied in the range 0 – 2600 Hz for each selected voltage in the range . When an experiment is running , the shape of the electrical wave , the frequency and amplitude are monitored all the time to ensure that there are no changes occurring due to the efficiency of the electronic kits used . There are several controlling knobs in the front panel , as shown in figure 4-2 a and b .This unit was used in all the experiments reported in this thesis .

II Determination of Critical Angle for The Detector Material :

It was mentioned in chapter 3 , that the critical angle is the minimum angle of incidence for the alpha particle to form countable track which does not disappear through the chemical or electro-chemical etching process . This value characterizes the detector material and it must be determined for radon

gas concentration to be calculated . To determine this angle for CR-39 used in this thesis , the unit shown in figure 4-4 was built . It is similar to the irradiation unit with the possibility of rotating the detector around circular scale to vary the angle of incidence in the range $0 - 90^{o}$.

III Parameters Affecting The detection System , Can – Technique :

After finding the optimum values for the ECE parameters , optimization study was carried out to find the best height and radius for the can . To do this , several groups of detection can systems have been prepared , each group has the same radius with different heights . These groups were fixed in the same location to ensure that they are exposed to the same radon concentration . To avoid statistical variations , the chosen location must have high radon concentration . A large cylindrical container closed from one end as shown in figure 4-5 , was designed for this purpose . Its open end was facing the ground and the different groups of cans were fixed in the middle of this container .

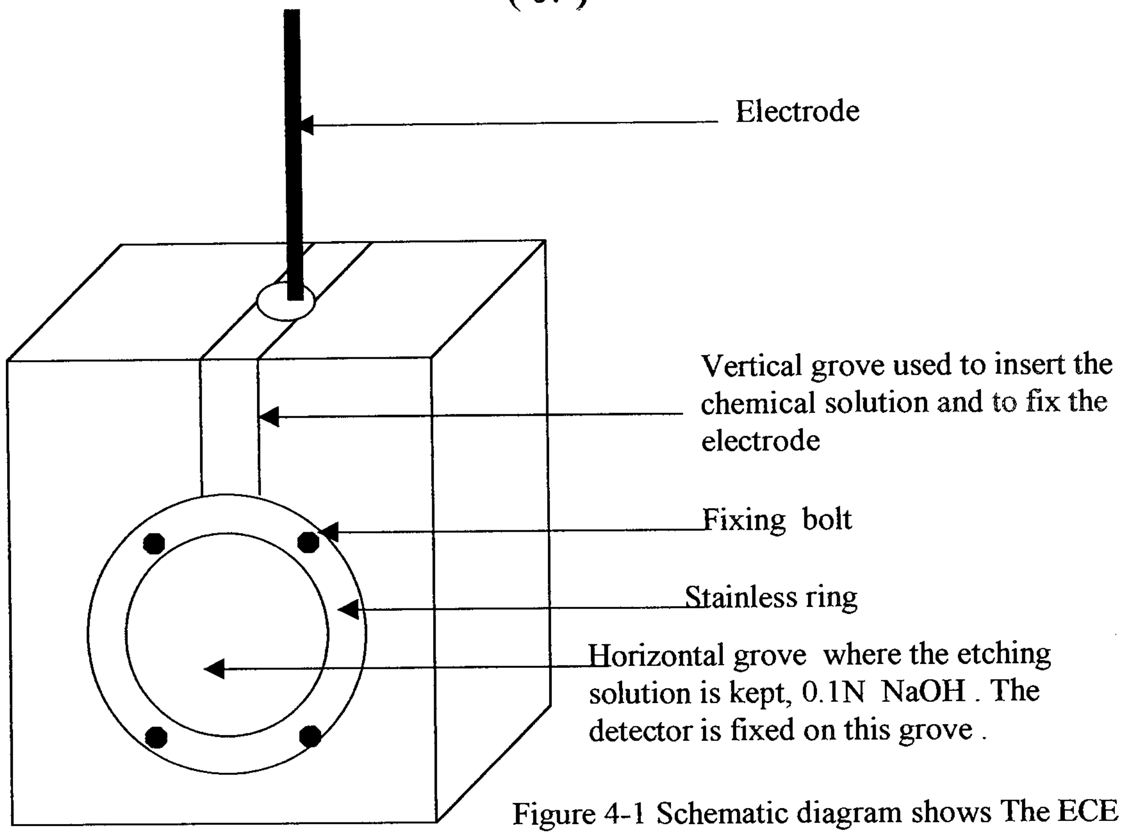


Figure 4-1 Schematic diagram shows The ECE cell

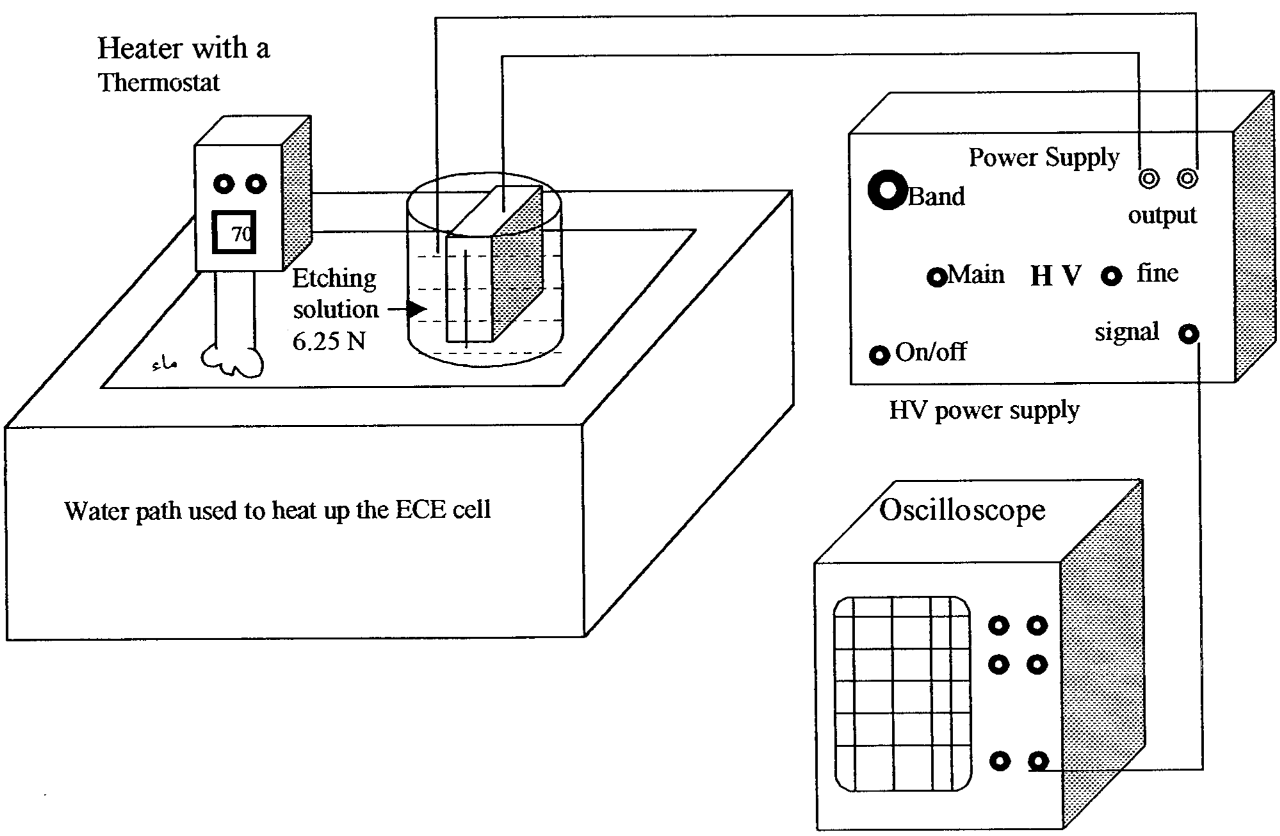


Figure 4-2 (a) : Schematic diagram shows the ECE equipments

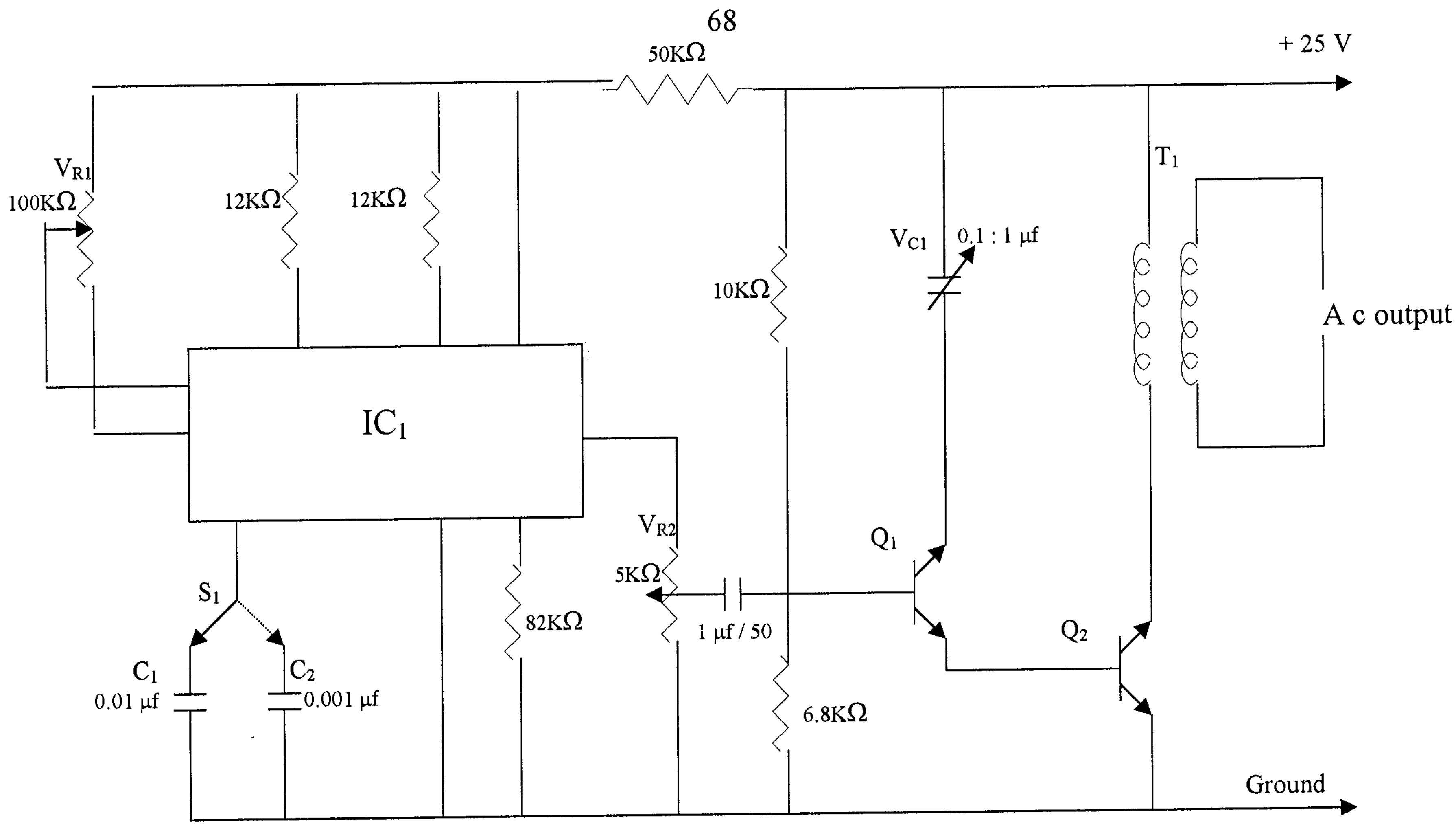


Figure 4-2 (b) : Power Function Generator

IC = ICL 8038 , Q_1 & Q_2 = 2N3055 , T_1 = Ferrit Cor Transformer P/S = 1 : 10

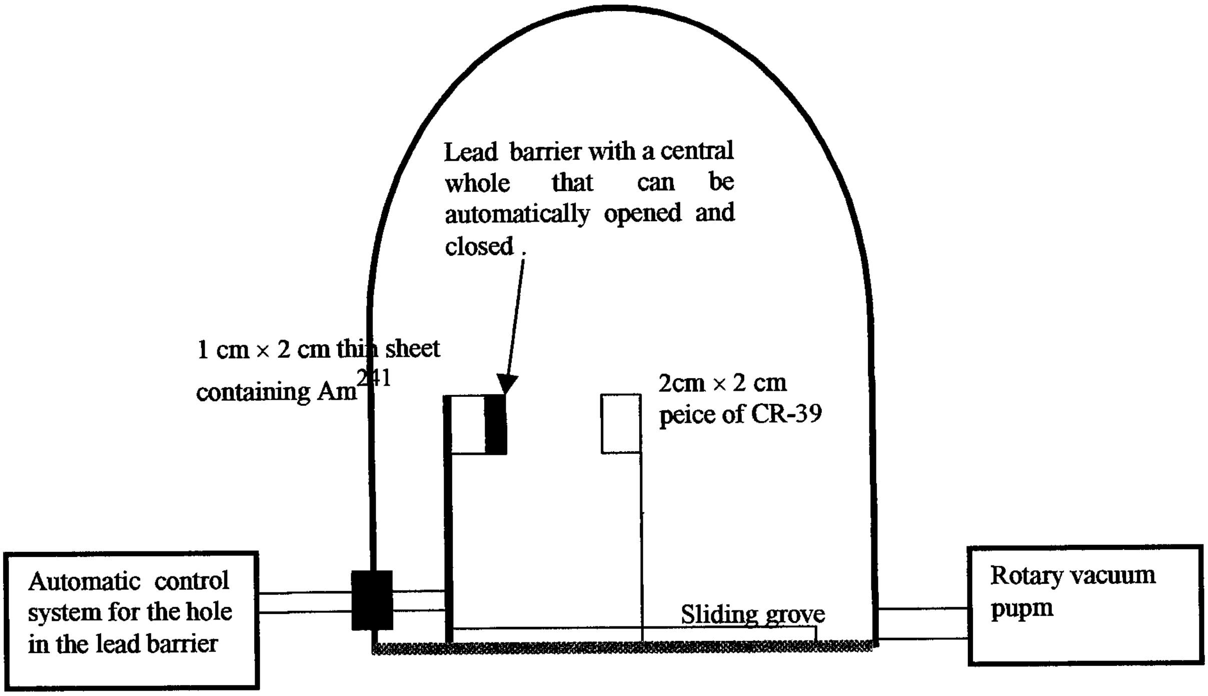


Figure 4-3 : Schematic diagram for the irradiation unit

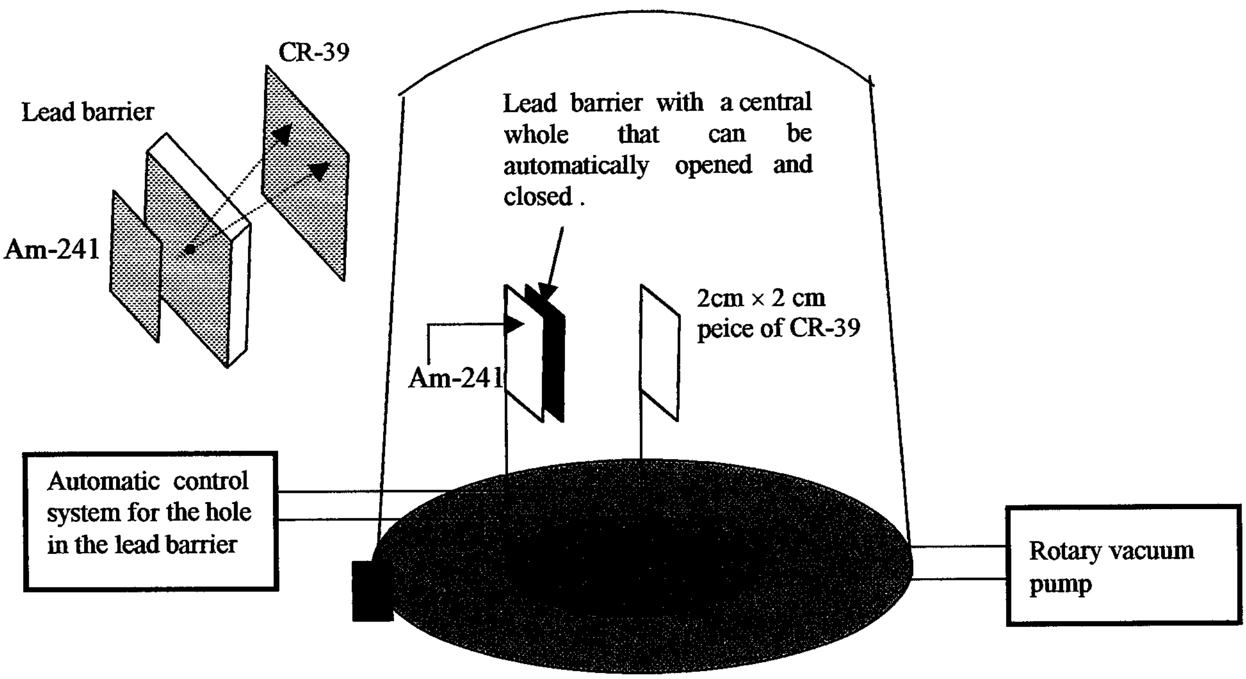


Figure 4-4 : Schematic diagram shows the critical angle measurement unit

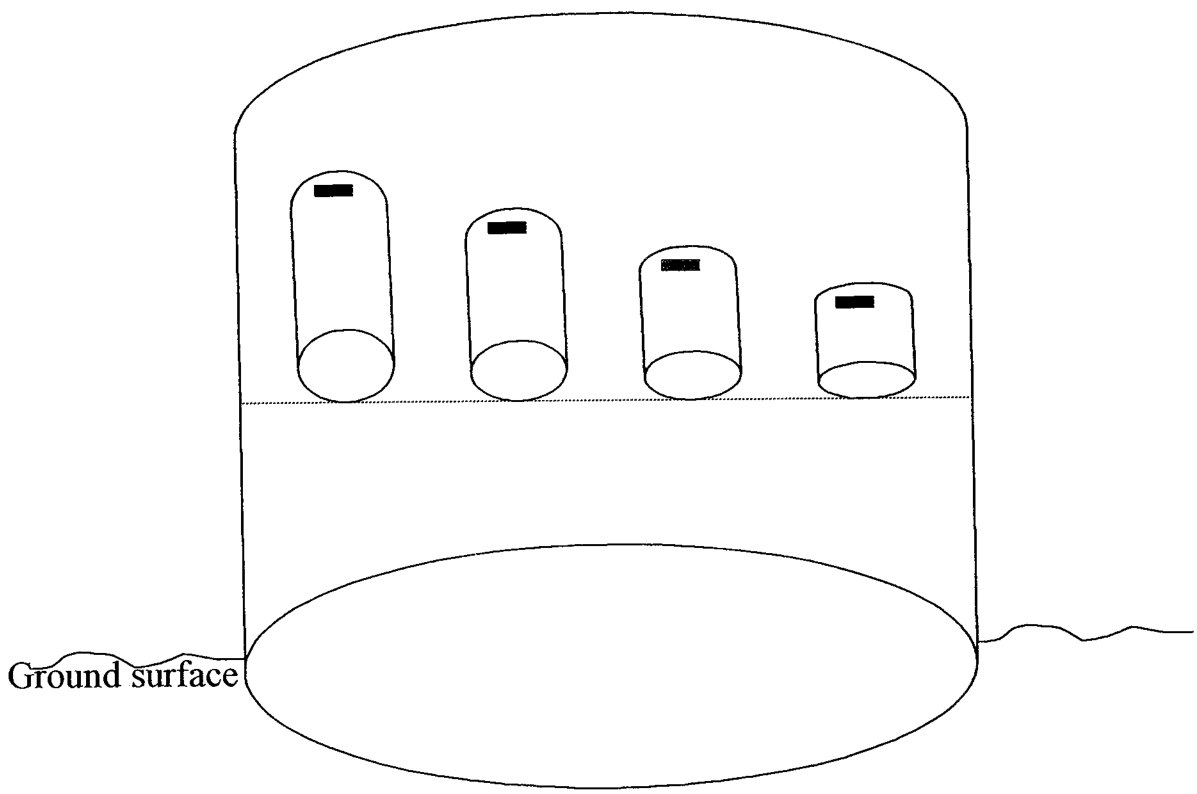


Figure 4-5 : Determination of best values of can height and radius

4-2-2 Field Measurements and Experimental Results :

In this section , we present the results of the experimental study which was carried out to find the optimum values for the parameters involved in this technique . 300 samples were used for this purpose . The results of field measurements carried out to estimate radon concentration in various places are also given . 120 samples were used for this purpose . The tracks were counted using an optical microscope connected to a screen and for each sample 10 fields of view were taken .

I The Results of The ECE optimization study :

Sufficient number of 2 cm × 2 cm pieces cut from the detector material were identically irradiated using the irradiation unit . These pieces were then electrochemically etched using the ECE equipments , under the following ECE condition : the voltage was varied in the range 1-5 k V for each frequency in the range 2.22 – 2.6 k Hz . Each measurement was repeated for ECE time in the range 0.5 – 3.5 hrs . Track diameter and track density were found for each piece using an optical microscope connected to a screen . For each piece , several field of view readings were taken and the average indicates the track density for that piece . Calibrated scaled slide was used to measure the dimension of the field of

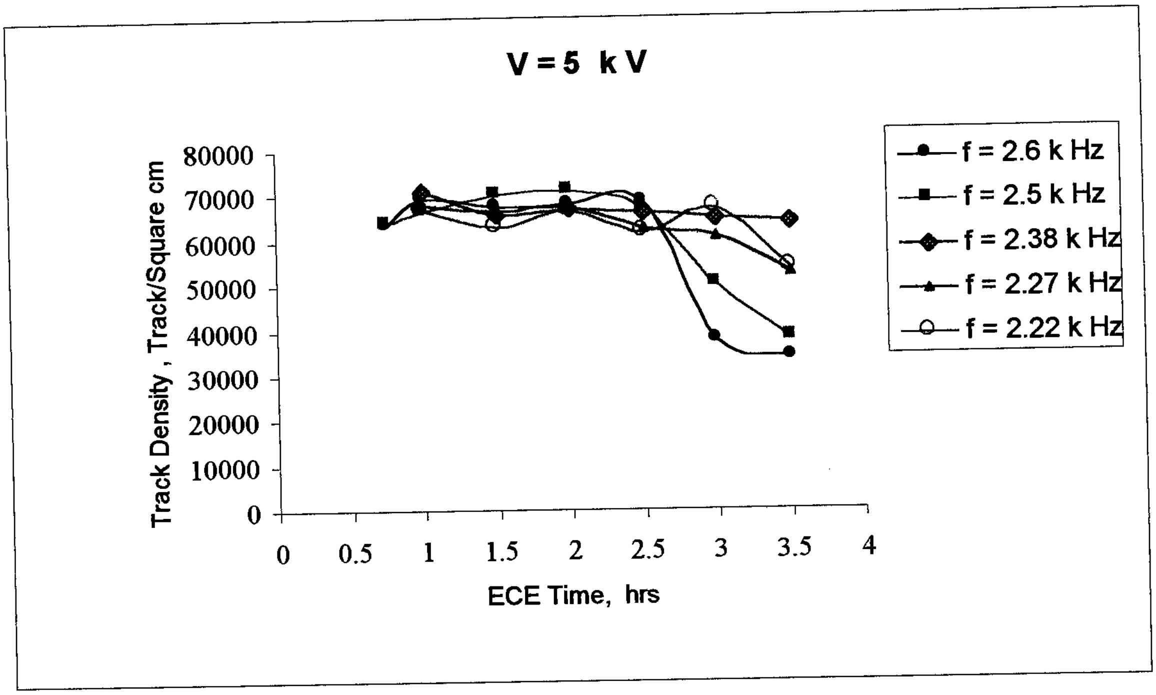
view . The ECE process was done using NaOH as an etchant solution . 0.1 N of this solution was injected in the ECE cell were the electrode is located . The role of this solution is to provide electrical conductivity for the electrical potential to be applied . There is no corrosion role for this solution because the side of the detector facing this solution has no tracks on it . The tracks are formed on the other side . The ECE cell is located in a beaker filled with 6.25 N of NaOH . The role of this solution is to provide electrical conductivity for the electrical potential to be applied as well as the corrosion of the side of the detector which contains the tracks . The beaker is kept in a water path at 70° C temperature . When all the equipments are correctly set , the electrical potential was applied and the pulse height , frequency and the shape of the sinusoidal wave were monitored during the whole period that the experiment is running using an oscilloscope . The results of these measurements are shown in figures from 4-6 up to 4-12 and tabulated in tables 4-1 up to 4-5 . The best values of the studied parameters are those values which give the highest track density and the best circular shape of the track . It can be seen that the best values for the voltage , frequency and ECE time can be taken as : 5 k V , 2.5 k Hz , 2 hrs . It was found that there is a linear relation between the ECE track diameter and the frequency , and between the diameter and the ECE time , see figure 4-6 , 4-11 , 4-12 .

II Determination of Critical Angle Study :

Sufficient number of 2 cm × 2 cm pieces cut from the detector material were identically irradiated at different angles of incidence beginning from very small angles using the unit designed for critical angle determination . These pieces were then electrochemically etched at the best ECE conditions 5 k V, 2.5 k Hz , 2hrs . The results of these measurements are shown in figure 4-13 and tabulated in table 4-6 . From these results , it can be seen that the critical angle is 10^{O} in agreement with results reported in literature [33] .

III The Results of The Optimization of the Can parameters :

Seventy 2 cm × 2 cm pieces were cut from the detector material and fixed in seventy cans , grouped according to their radii in the range 2-11 cm . Each group contains cans with different heights in the range 2-20 cm . These cans are fitted inside the large cylindrical container shown in figure 4-5 . The results of these measurements are shown in figure 4-14 and tabulated in table 4-7 . The best values are those values which give the highest track density . It can be seen that the best can diameter is 7 cm and the best can height is 4 cm .



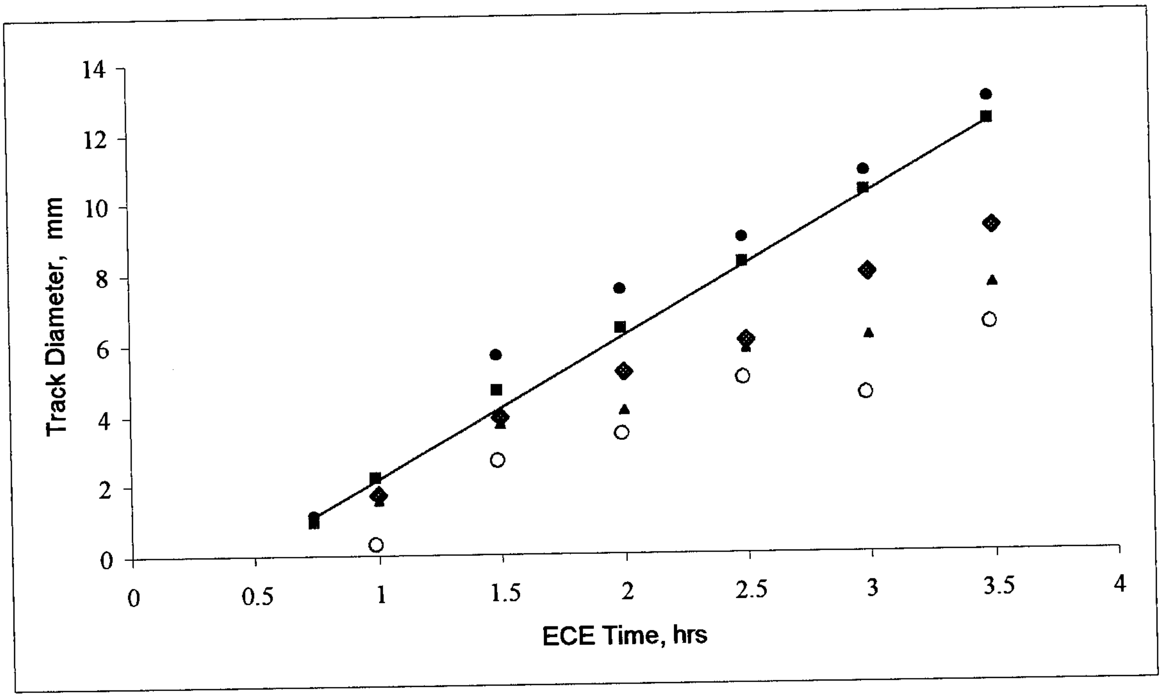
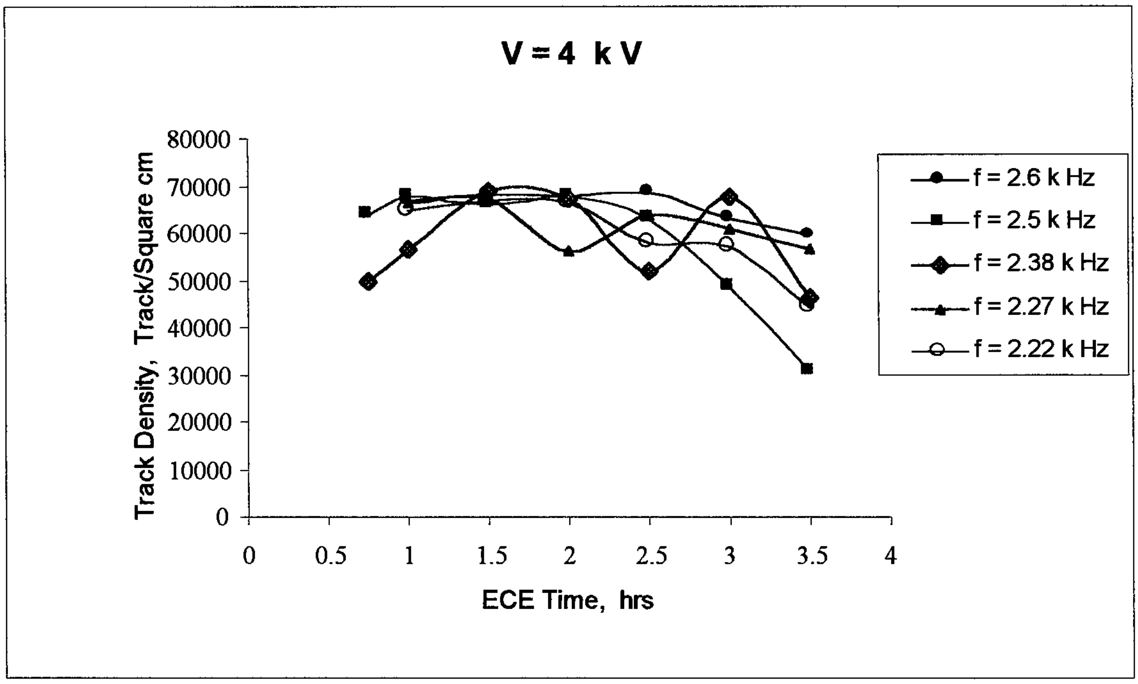


figure 4-6 : The effect of the frequency and ECE time on track density and track diameter at voltage V = 5 k V



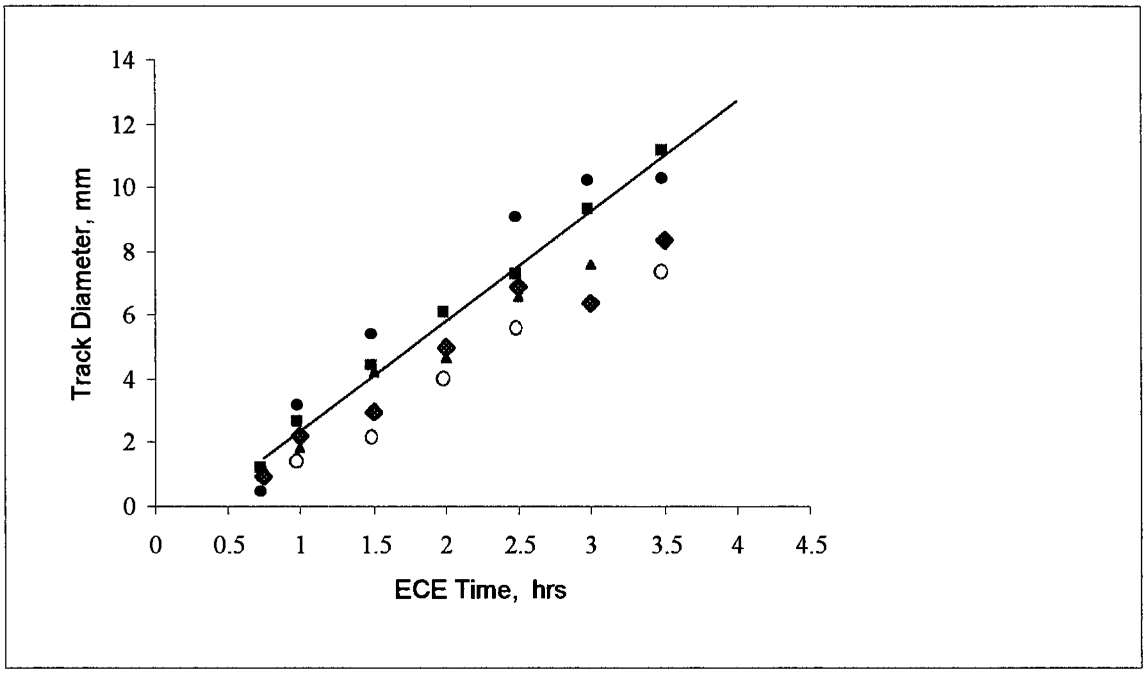
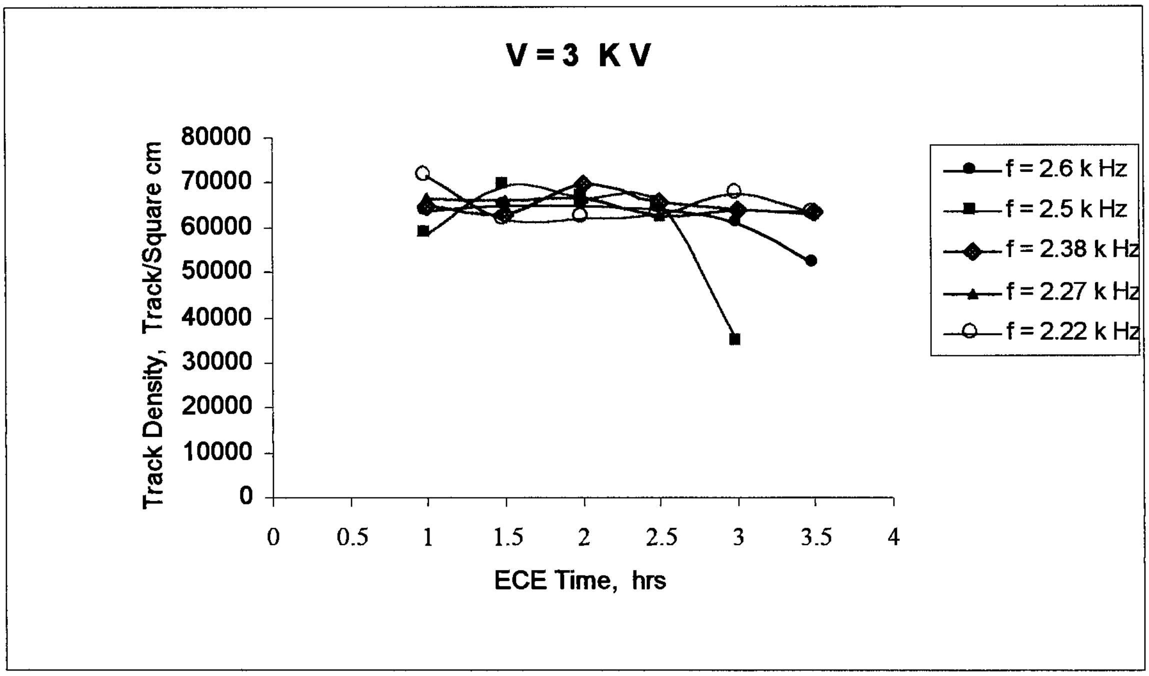


figure 4-7 : The effect of the frequency and ECE time on track density and track diameter at voltage V = 4 k V



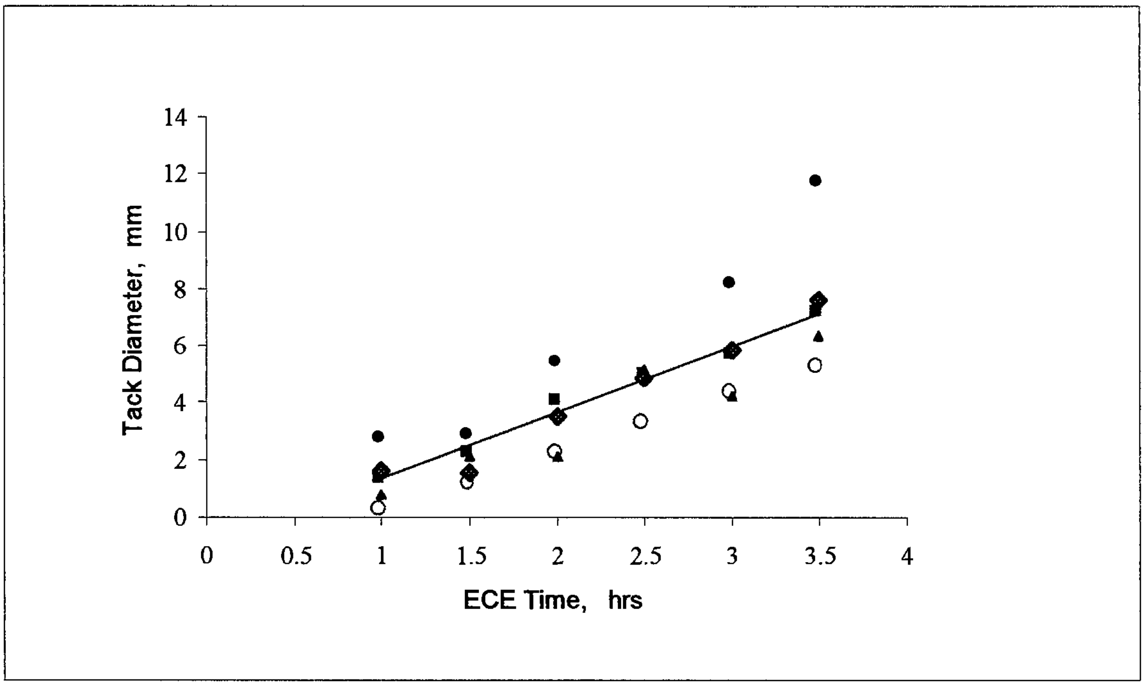
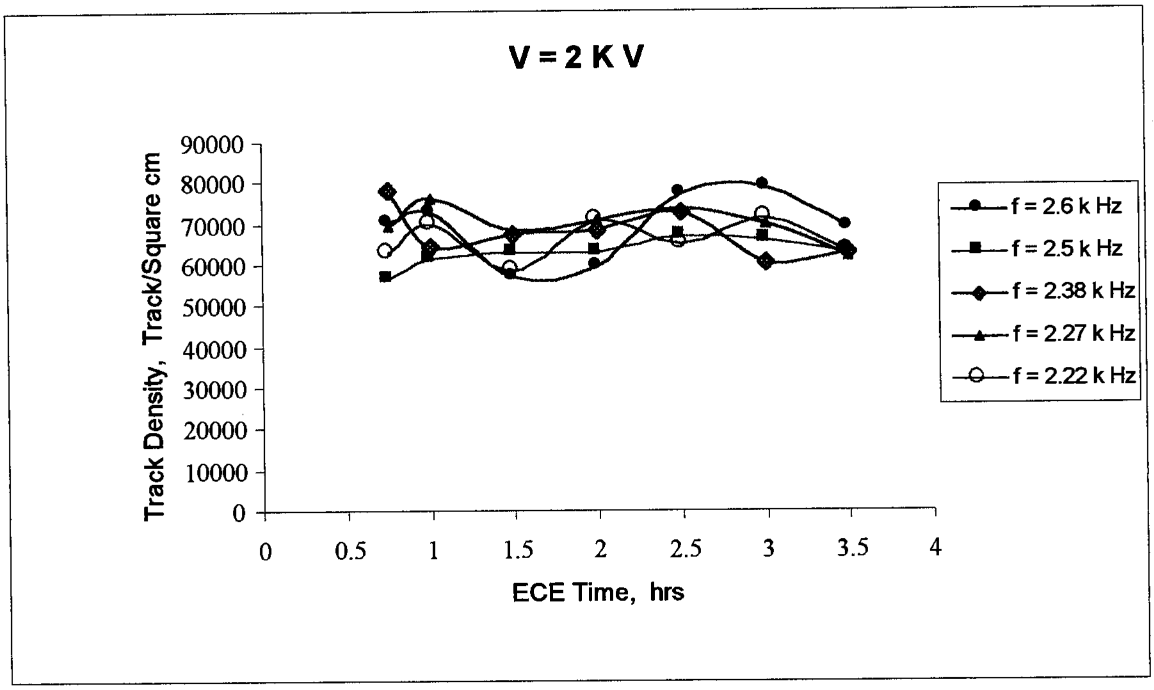


figure 4-8 : The effect of the frequency and ECE time on track density and track diameter at voltage V = 3 k V



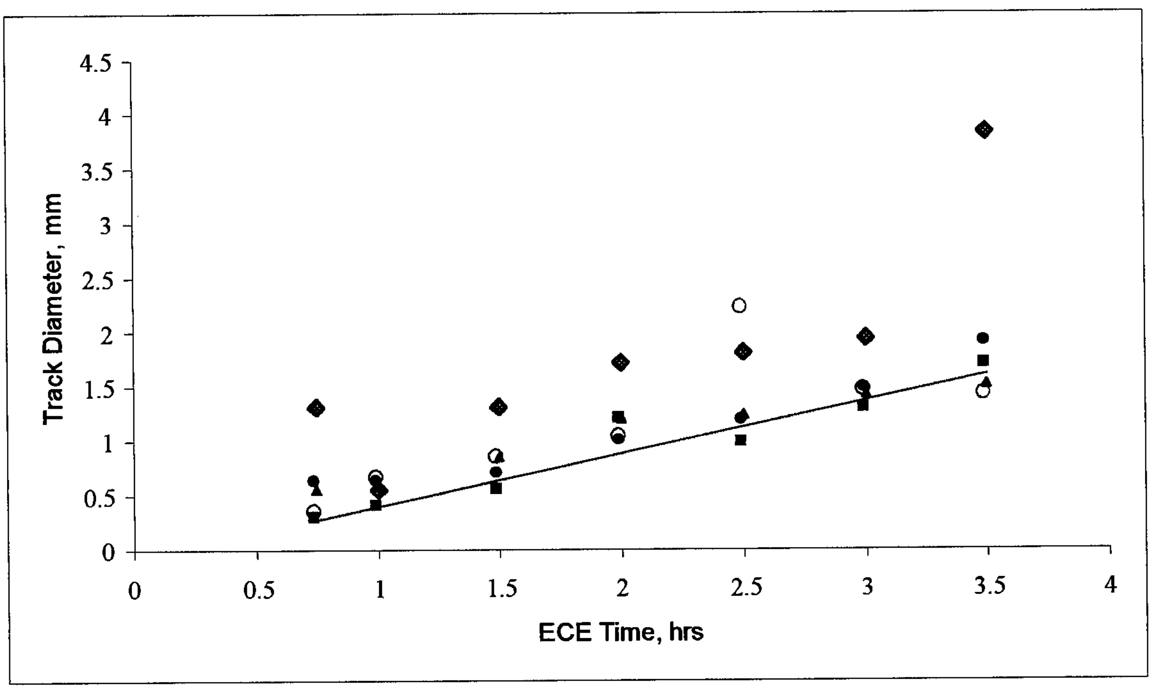
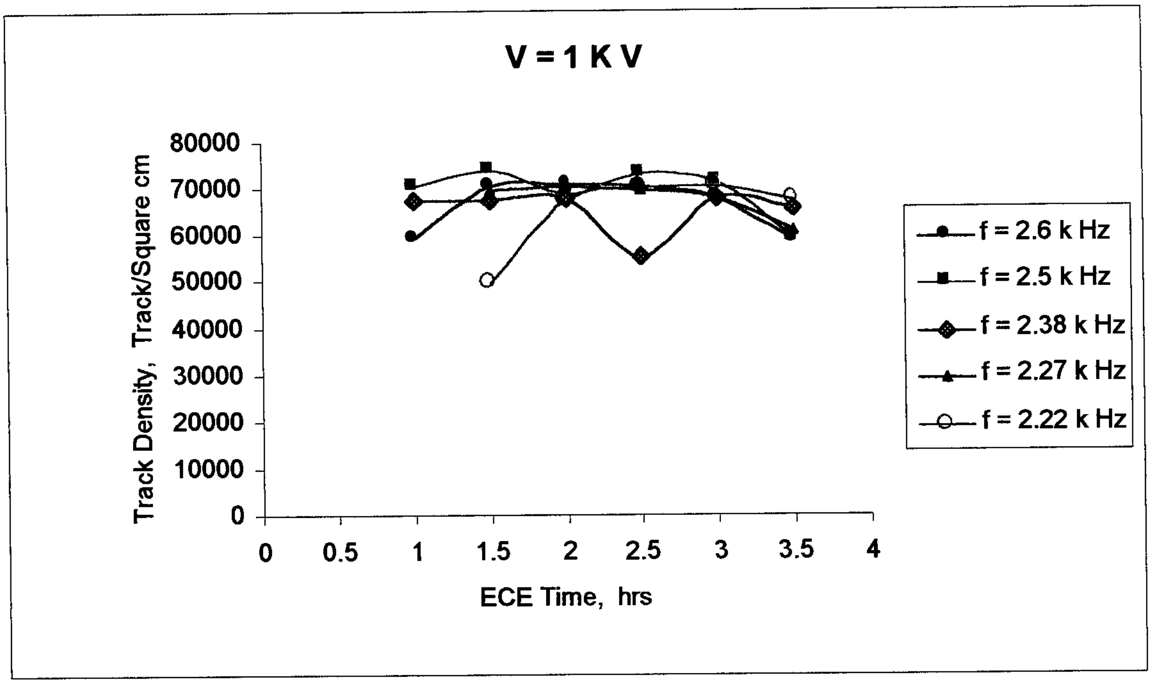


figure 4-9 : The effect of the frequency and ECE time on track density and track diameter at voltage V =2 k V



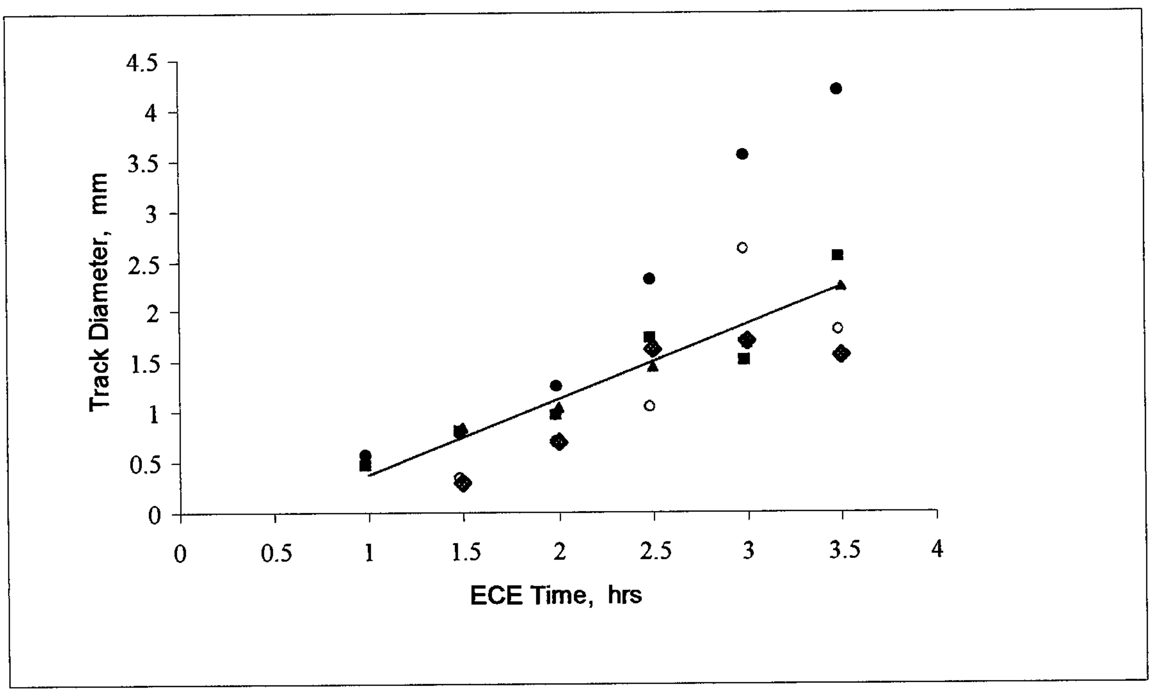
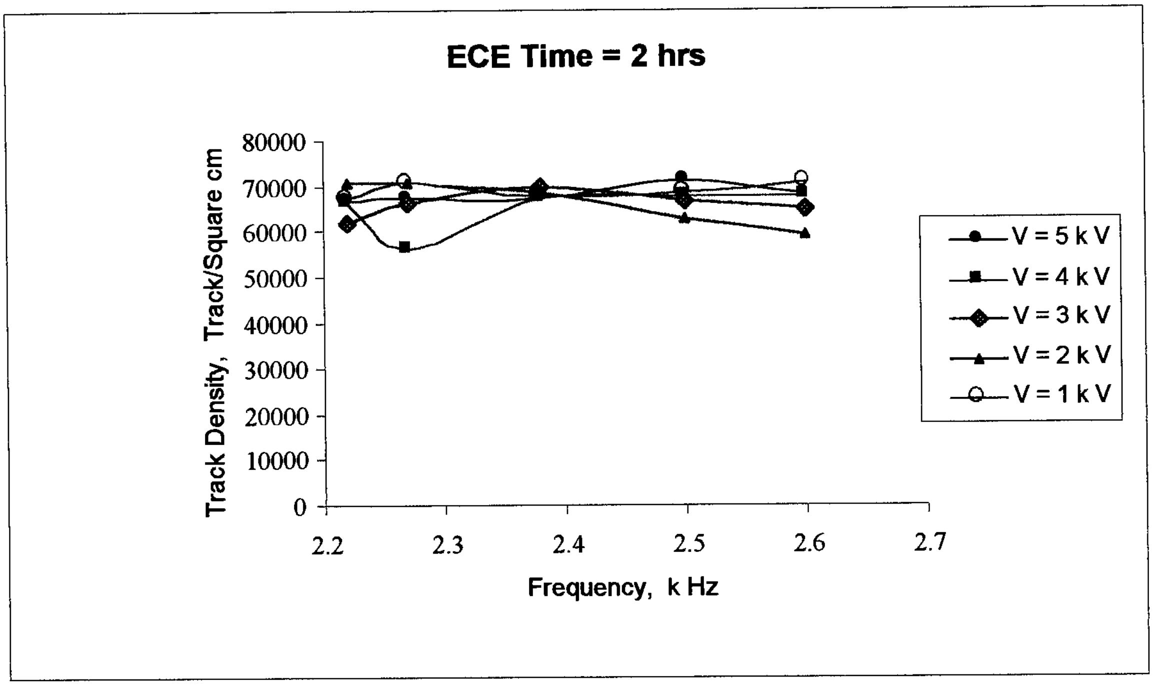


figure 4-10 : The effect of the frequency and ECE time on track density and track diameter at voltage V =1 k V



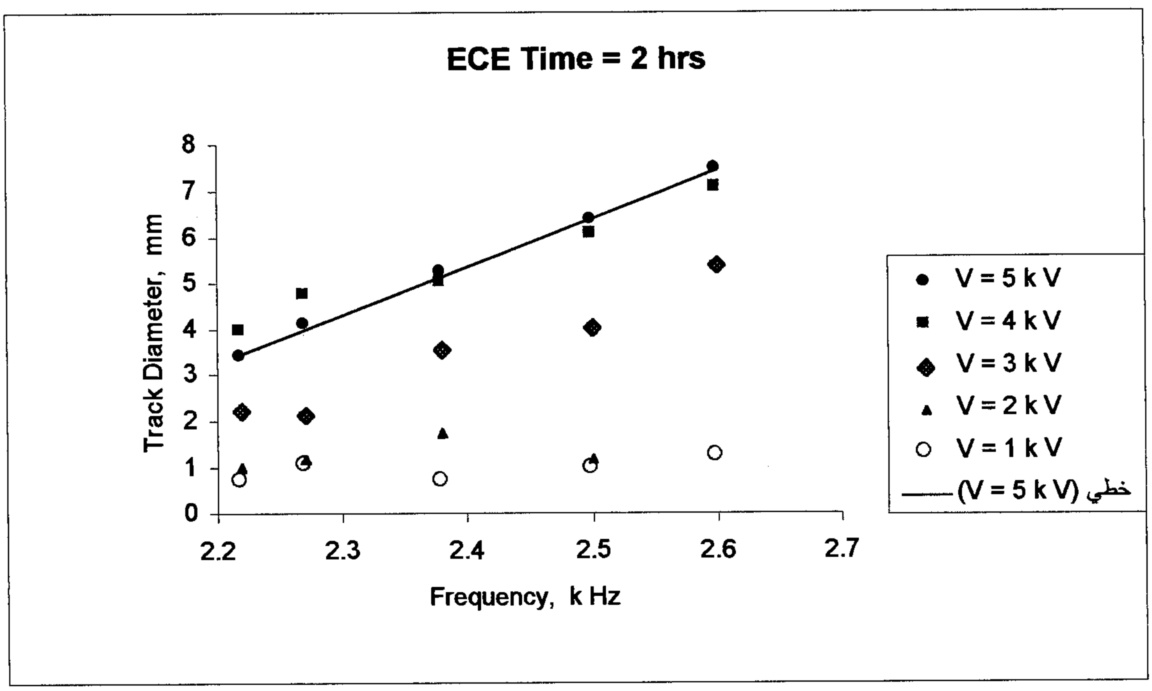
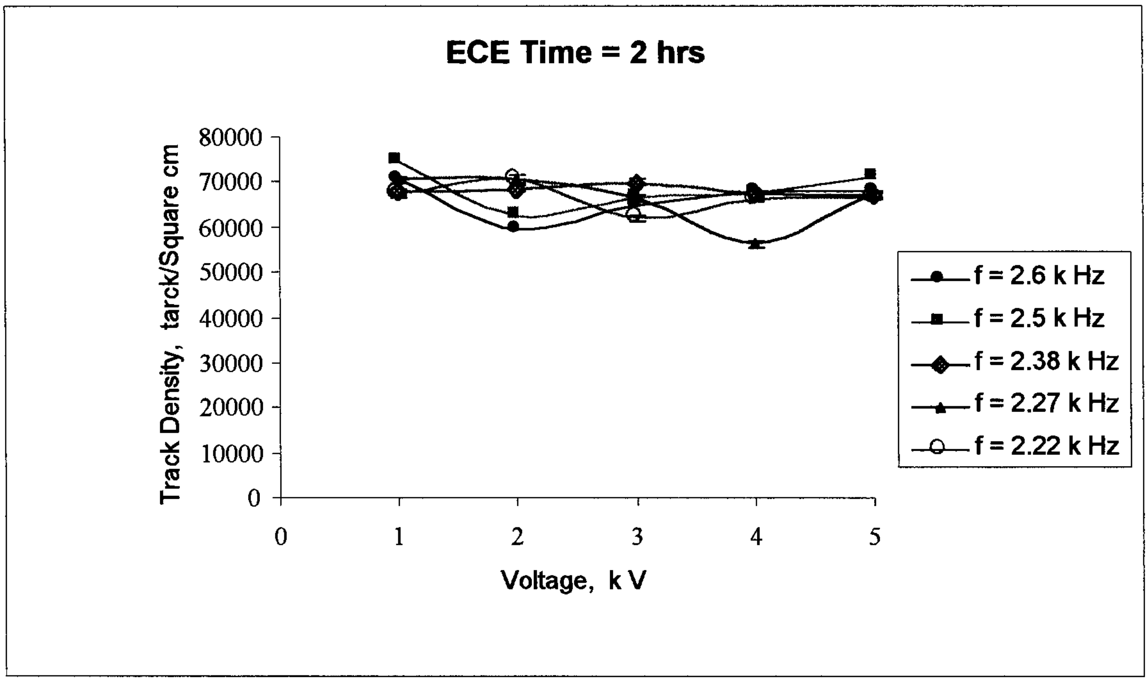


figure 4- 11 : The relation between frequency and track density , Frequency and track diameter at different voltages at ECE time = 2 hrs



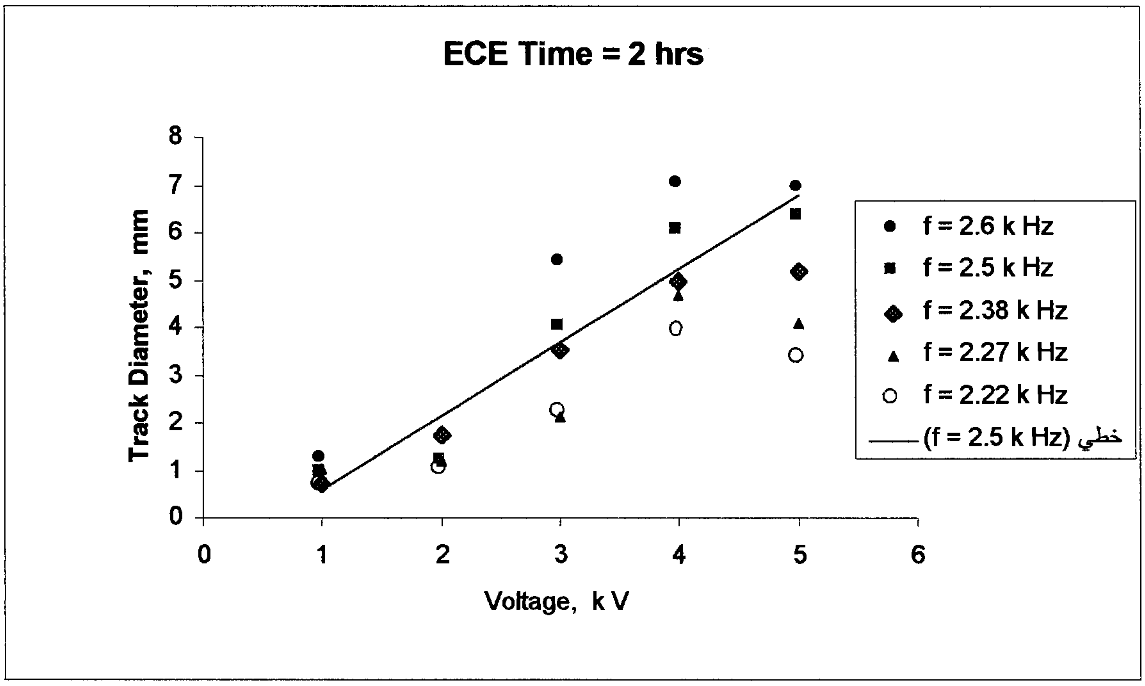


Figure 4-12 : The relation between voltage and track density , voltage and track diameter at diffrernt frequencies at ECE time = 2 hrs

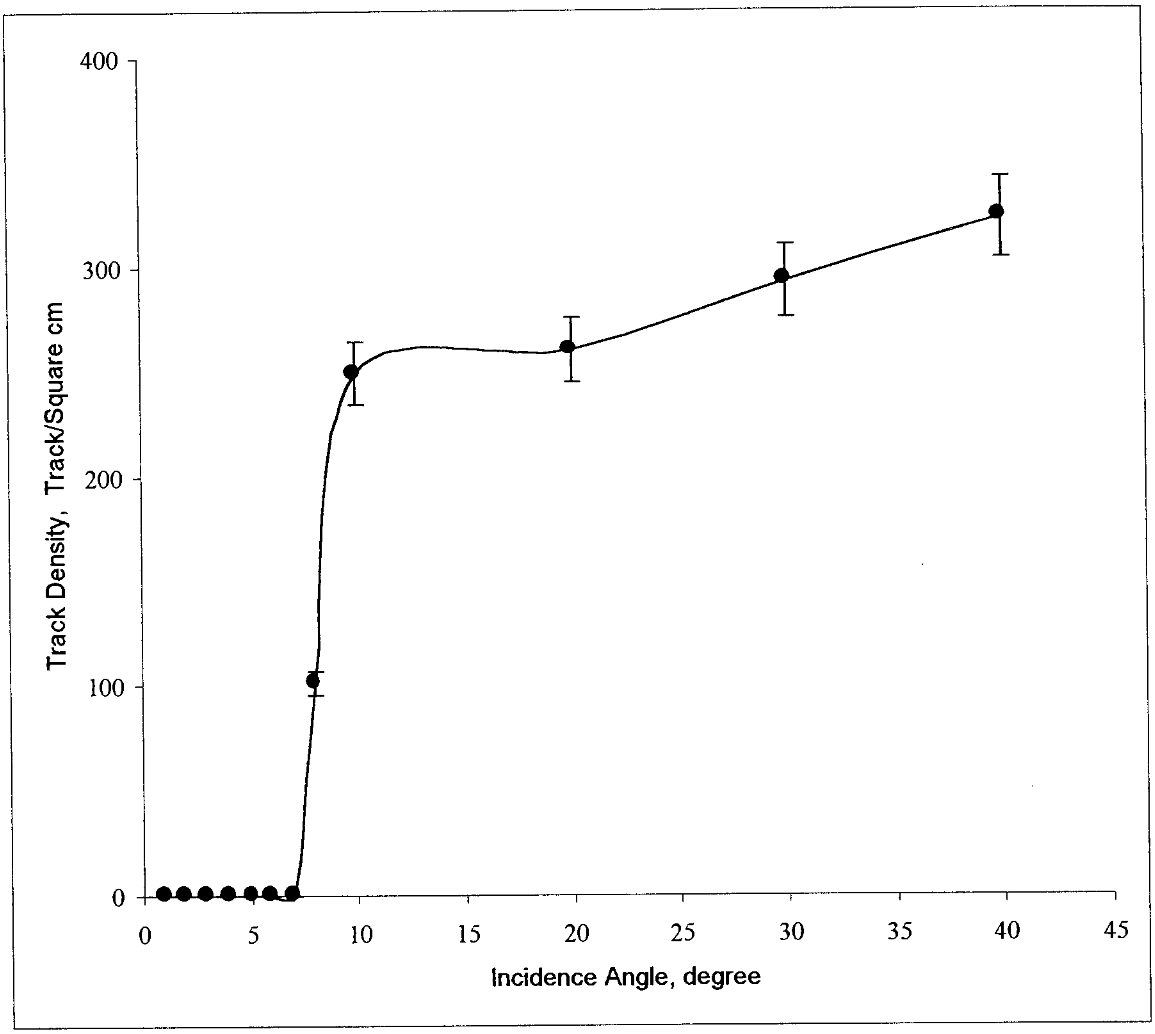
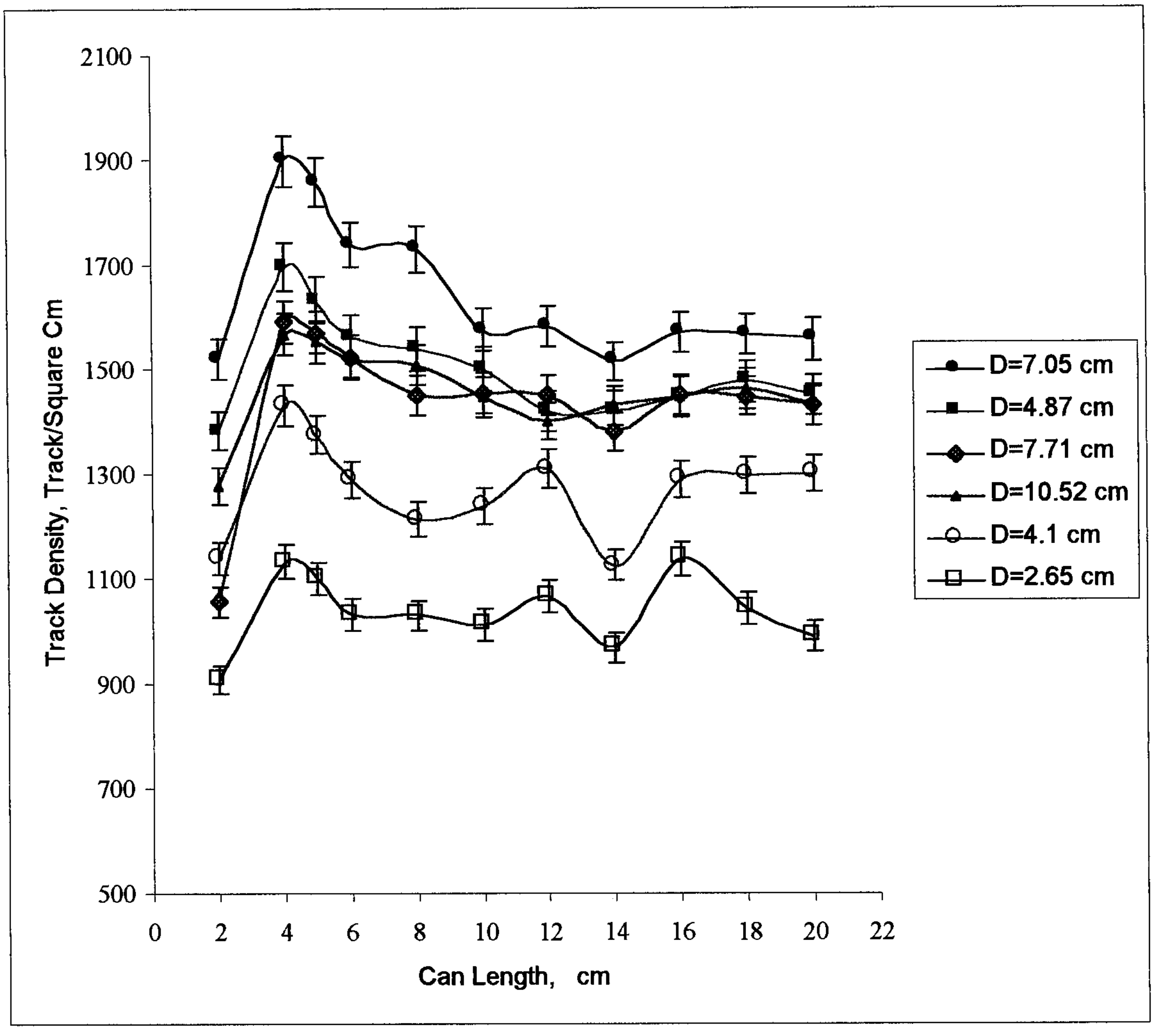


Figure 4- 13 : Determination of the critical angle of the detector material .



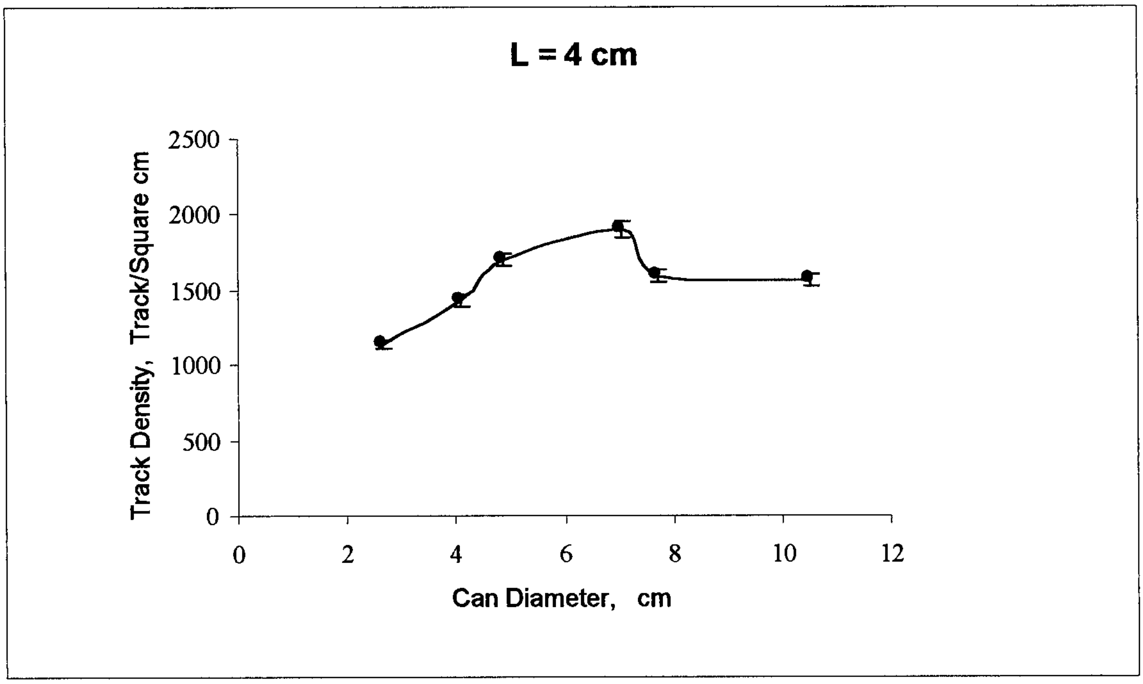


Figure 4-14 : Determination of the best values for can height and length .

Table 4-1 : Values of track density and track diameter as a function of ECE time at 5 k V for different frequencies .

F=2.22k Hz		F=2.27k Hz		F=2.38 k Hz		F=2.5 k Hz		F=2.6 k Hz		Time hrs
diameter, mm	Track density, Track/cm^2	diameter, mm	Track density, Track/cm^2	Diameter, mm	Track density, Track/cm^2	Diameter, mm	Track density, Track/cm^2	Diameter, mm	Track density, Track/cm^2	
-	-	-	-	-	-	0.89	63952±253	1.02	63380±252	0.75
0.26	67097±259	1.56	67758±260	1.74	71007±266	2.11	66446±258	2.15	69356±263	1
2.61	62883±251	3.75	66761±258	3.91	65739±256	4.60	70197±265	5.57	67519±260	1.5
3.36	66808±258	4.08	67401±260	5.20	66997±259	6.32	71142±267	7.422	68066±261	2
4.92	61764±249	5.84	62486±250	6.02	66368±258	8.19	66839±259	8.89	68412±262	2.5
4.42	66890±259	6.16	60706±246	7.92	64638±254	10.23	49966±224	10.71	37745±194	3
6.38	53520±231	7.63	52528±229	9.21	63761±253	12.17	37902±195	12.78	33691±184	3.5

Table 4-2 : Values of track density and track diameter as a function of ECE time at 4 k V for different frequencies .

F=2.22 k Hz		F=2.27 k Hz		F=2.38 k Hz		F=2.5 k Hz		F=2.6 k Hz		Time hrs
diameter, mm	Track density, Track/cm^2	diameter, mm	Track density, Track/cm^2	Diameter, mm	Track density, Track/cm^2	diameter, mm	Track density, Track/cm^2	diameter, mm	Track density, Track/cm^2	
-	-		-	0.96	49641±223	1.15	63788±253	0.38	-	0.75
1.34	64543±254	1.82	66261±257	2.21	56527±238	2.58	67815±260	3.12	66997±259	1
2.097	66787±258	4.24	67075±259	2.97	68727±262	4.37	65896±257	5.35	67940±261	1.5
3.92	66210±257	4.70	56177±237	4.97	67311±259	6.03	67519±260	6.02	67815±260	2
5.50	58001±240	6.57	63694±252	6.93	52025±228	7.21	62782±251	8.98	68399±262	2.5
	57018±239	7.58	60706±246	6.38	67450±260	9.27	48313±220	10.10	62998±251	3
7.30	44125±210	8.34	56585±238	8.37	46426±215	11.09	31454±177	10.23	59611±244	3.5

Table 4-3 : Values of track density and track diameter as a function of ECE time at 3 k V for different frequencies .

F=2.22 k Hz		F=2.27 k Hz		F=2.38 k Hz		F=2.5 k Hz		F=2.6 k Hz		Time
diameter, mm	Track density, $Track/cm^2$	diameter, mm	Track density, $Track/cm^2$	Diameter, mm	Track density, $Track/cm^2$	diameter, mm	Track density, $Track/cm^2$	diameter, mm	Track density, $Track/cm^2$	hrs
0.21	71500±267	0.77	66393±258	1.64	64613±254	1.28	58712±242	2.68	63411±252	1
1.15	61500±248	2.11	66053±257	1.59	63222±251	2.22	69344±263	2.83	64716±254	1.5
2.21	62000±249	2.15	66431±257	3.54	69841±264	4.05	66617±258	5.37	65005±255	2
3.22	63000±251	5.15	62694±250	4.88	65594±256	4.95	65046±255	4.85	63694±252	2.5
4.3	67500±260	4.23	64086±253	5.88	64021±253	5.68	34520±186	8.16	60912±247	3
5.21	63000±251	6.36	62845±251	7.62	63537±252	7.17	-	11.66	52034±228	3.5

Table 4-4 : Values of track density and track diameter as a function of ECE time at 2 k V for different frequencies

F=2.22 k Hz		F=2.27 k Hz		F=2.38 k Hz		F=2.5 k Hz		F=2.6 k Hz		Time
diameter, mm	Track density, $Track/cm^2$	diameter, mm	Track density, $Track/cm^2$	Diameter, Mm	Track density, $Track/cm^2$	diameter, mm	Track density, $Track/cm^2$	Diameter, mm	Track density, $Track/cm^2$	hrs
0.34	62782±251	0.56	69198±263	1.32	78006±279	0.27	56639±238	0.61	70267±265	0.75
0.64	69906±264	0.6	76276±276	0.55	64373±254	0.39	61252±247	0.61	72816±270	1
0.84	58712±242	0.85	68277±261	1.32	67499±260	0.54	62753±251	0.68	57275±239	1.5
1.02	70614±266	1.2	70645±266	1.73	68569±262	1.19	62753±251	0.99	59312±244	2
2.2	64795±255	1.24	73703±271	1.82	72816±270	0.96	66907±259	1.17	77376±278	2.5
1.44	71403±267	1.43	69985±265	1.95	60706±246	1.27	66037±257	1.46	78823±281	3
1.4	63065±251	1.52	61964±249	3.84	63128±251	1.69	62896±251	1.88	69073±263	3.5

Table 4-5 : Values of track density and track diameter as a function of ECE time at 1 k V for different frequencies

F=2.22 k Hz		F=2.27 k Hz		F=2.38 k Hz		F=2.5 k Hz		F=2.6 k Hz		Time
diameter, mm	Track density, Track/cm^2	diameter mm	Track density, Track/cm^2	Diameter mm	Track density, Track/cm^2	diameter mm	Track density, Track/cm^2	diameter mm	Track density, Track/cm^2	hrs
-	-	-	-	-	67563±260	0.45	70457±265	0.54	59133±243	1
0.33	49539±223	0.84	69702±264	0.29	67437±260	0.79	74105±272	0.77	70457±265	1.5
0.68	67311±259	1.04	70557±266	0.71	67726±260	0.95	68674±262	1.22	70771±266	2
1.02	69932±264	1.44	69614±264	1.63	55359±235	1.70	73074±270	2.3	70457±265	2.5
2.59	70299±265	1.69	67726±260	1.71	68045±261	1.49	71528±267	3.52	67784±260	3
1.79	67311±259	2.25	61146±247	1.57	65783±256	2.51	59313±243	4.16	58923±243	3.5

Table 4-6 : Results of Critical angle measurements

Track density, Track/cm	Angle of incidence ,degree
0	1
0	2
0	3
0	4
0	5
0	6
0	7
101 ± 10	8
245 ± 15.7	10
260 ± 16	20
293 ± 17	30
323 ± 18	40

Table 4-7 : Results of the effect of can height and diameter study

Track density, Track/cm^2						Can height
D=2.65 cm	D=4.1 cm	D=4.87 cm	D=7.05 cm	D=7.71 cm	D=10.52 cm	cm
908 ± 30	1138 ± 34	1382 ± 37	1520 ± 39	1056 ± 32	1277 ± 36	2
1132 ± 34	1429 ± 38	1697 ± 41	1899 ± 44	1591 ± 40	1567 ± 40	4
1100 ± 33	1375 ± 37	1632 ± 40	1857 ± 43	1571 ± 40	1553 ± 39	5
1031 ± 32	1290 ± 36	1560 ± 39	1739 ± 42	1524 ± 39	1520 ± 39	6
1029 ± 32	1212 ± 35	1538 ± 39	1729 ± 42	1450 ± 38	1507 ± 39	8
1012 ± 32	1239 ± 35	1500 ± 39	1575 ± 40	1454 ± 38	1447 ± 38	10
1067 ± 33	1309 ± 36	1421 ± 38	1581 ± 40	1450 ± 38	1400 ± 37	12
968 ± 31	1125 ± 34	1421 ± 38	1514 ± 39	1380 ± 37	1430 ± 38	14
1137 ± 34	1288 ± 36	1447 ± 38	1570 ± 40	1450 ± 38	1447 ± 38	16
101 ± 10	1295 ± 36	1476 ± 38	1565 ± 40	1448 ± 38	1461 ± 38	18
990 ± 31	1301 ± 36	1450 ± 38	1556 ± 39	1431 ± 38	1430 ± 38	20

IV Indoor Radon measurements :

Comparative measurements were carried out at the beginning to check our detection system . Two types of radon dosimeters were used , one of them is designed and calibrated by the British National Radiation Protection Board NRPB [14] , and the other one belongs to the faculty of engineering in King Abdul – Aziz University . Figure 4-15 shows schematic diagram for the NRPB dosimeter . It is made of plastic and have the shape of half sphere with circular base 7cm diameter and 4cm height . It uses the CR-39 as a detection material . Radon concentration is given in terms of track density through an empirical formula of the form [65] :

$$C_{Rn} = 10.93\ \rho / T \qquad (4\text{-}1)$$

The detection system designed locally and the NRPB dosimeter were prepared and then located together in 37 places and left for 30 days . ECE process was made for both detectors and the track density for each detector was extracted using Eq. 3-25 and 4-1 respectively . Measurement results are shown in table 4-8 and it indicates good agreement between the two detection systems .

Figure 4-16 shows schematic diagram for King abdul-Aziz University detection system . It is made up of a properly closed cylindrical container plastic with circular base 8.5 cm diameter and 3 cm height . It uses charcoals granules as a detection material . A piece of sponge is fitted on top these granules to keep them in position . Radon and radon daughters atoms are precipitated on the charcoal and radon concentration is extracted through gamma spectroscopic analysis . Measurement results are shown in table 4-9 and they also indicate a fair agreement between the two detection systems .

Sixty six units of the local detection system are then prepared with best can height and diameter ; i.e. 7 cm and 4 cm respectively and were fixed inside the bedrooms of houses in different districts of Makkah (In each location more than one detection system were fixed) . They were left for 30 days and then collected . ECE process was carried out at the best conditions : 5 k V, 2.5 k Hz , 2 Hrs , then track densities were determined , and the average value for each location was taken . Bedrooms are chosen because they are most likely to be least ventilated .

On the other hand , the hot weather in Makkah increases the dependence on air conditioning systems that require keeping all windows closed which may lead to bad ventilation .

The indoor measurements were done in summer and in winter in some locations , to check the temperature effect .

Makkah has a large number of tunnels cut through the mountains , so some of these detection systems were fixed inside the tunnels to measure the radon level there .

The results of the measurements are shown in tables 4-10 up to 4-13 , where all values are rounded to the nearest integer and standard deviation is calculated for the average value. Table 4-10 shows indoor radon concentrations . The highest value was 91 Bq / m^3 recorded in Ree Al-Kohl . The lowest value was 14 Bq / m^3 recorded in Al-Beeban . The average value for indoor concentration is 56±23 Bq / m^3 . However , it can be seen that radon concentration largely varies from one district to another and that could be attributed to the properties of the location itself such as : the area of bedroom and its windows, air conditioning and ventilation method .

Table 4-11 shows radon concentrations in the Mashaer mosques . The highest value was 55 Bq / m^3 recorded in Al-Khaif mosque in mina . The second higher value is 49 Bq / m^3 recorded in Nmira mosque . This is expected because these two mosques are kept closed most of the year . They are opened during Haj period for about three months only . The lowest value was 15 Bq / m^3 recorded in Al-Haram due to good ventilation resulting from huge area and very high ceilings i.e. large air volume . The average value in these mosques is 40±22 Bq / m^3 .

Table 4-12 shows radon concentrations in the tunnels . The highest value was 67 Bq / m^3 Jabal Al-Kaba tunnel . The lowest value was 41 Bq / m^3 recorded in Ajiyad tunnel . The rocks of the mountains through which tunnels are cut , may contain U^{238} , so radon concentration is expected to be high . These tunnels have open ends and the powerful sucking systems fitted inside them may play an important role in reducing radon concentration . The average value in these tunnels is 52 ±13 Bq / m^3 .

Table 4-13 shows radon comparison between indoor radon concentrations in the summer and in winter (inside bedrooms) . It can be seen that there is a slight increase in the radon concentration during winter. That is expected because the high room temperature makes radon gas diffuses in the room occupying larger volume which reduces the concentration. As mentioned before , the effect of room and windows area , method of air-conditioning and ventilation may dominate the effect of seasonal changes in room temperature .The average value in summer was 48 ± 14.5 Bq / m^3 and in the winter is 60 ± 14.5 Bq / m^3 in the houses under consideration .

Comparing the results of the present work with the published , which also showed large variation , it can be seen that there is good agreement between them . The measurements of radon concentration in various cities in Saudi arabia carried out by Abu-jarad and Al-jarallah [5 , 11] , and Mamoon and Abdul Fattah [12] showed that radon concentration lies in range : 0.13 pCi / L – 2.2 pCi / L which is equivalent to 4.8 Bq/m^3 - 81.4 Bq/m^3 (1pCi = 37 Bq/m^3) . The average value of indoor radon concentration in Makkah is 56 ± 23 Bq/m^3 .

Summary of Some Published Data for Average Indoors Radon concentrations

Location	Average Radon Concentration Bq / m^3	Ref.
Saudi Arabia :		
Khobar	10	[11]
Tayef	36	[11]
Jeddah	81	[12]
Riyadh	16	[14]
U K	20	[66]
Italy	55	[66]
China	26	[62]
West Germany	49	[66]
USA	61	[66]
France	76	[66]
France(Alpes Maritimes)	34	[66]
Ireland	68	[66]
Denmark	68	[66]
Netherlands	31	[66]
Poland	9	[66]
Switzerland	89	[66]
Finland	90	[66]
Japan	10	[66]
Norway	90	[66]
Canda	33	[66]
Sweden	100	[66]
Egypt (Alexandria)	33	[67]
Makkah	56	present work

Dose equivalent resulting from the exposure to indoor radon can be calculated using equations 3-26 , 3-27 , 3-28 assuming that ordinary person spends 19 hrs inside houses (12 hours in light and 7 hours sleeping) according to table 3.1 and taking F = 0.4 , we get :

$$H = 0.01 \times 0.4 \times (56/37) \times 1.3 \times 10^5 \times 18.72 \times 10^3 \times 365 \times 1.6 \times 10^{-13} \times 20$$

$$= 17.2 \ \text{m Sv / year}$$

Since lung is the most probable organ to be affected by radon gas and its daughters , then the annual effective equivalent dose H_E is :

$$H_E = 17.2 \times 0.12 = 2.06 \ \text{m Sv / year}$$

Table 4-8 : Comparison between the results of the measurements carried out by the local detection system and the NRPB dosimeter .

Location	Radon concentration Bq / m^3	
	NRPB system	Local system
Jarwal	62	65
Al-Zahir	58	60
Hindaweyyah	51	56
Al-Aziziyah	50	54
Namira Mosque	48	49

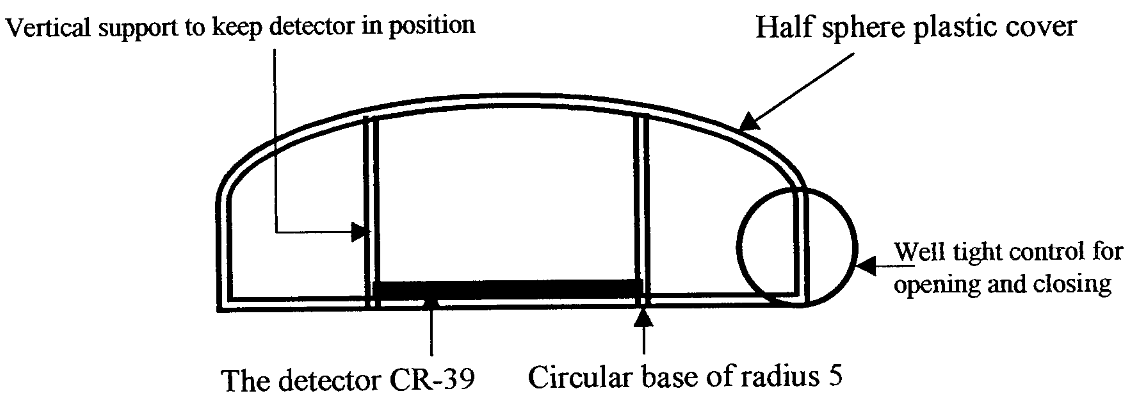


Figure 4-15 : Schematic diagram shows the design of the NRPB detection system [15]

Table 4-9 : Comparison between the results of the measurements carried out by the local detection system and King Abdul Aziz University system .

Location	Radon concentration Bq / m^3	
	King Abdul Aziz University system	Local system
Al-Rosaifah	58	66
Al-Misfalah	42	39
Al-Beeban	18	14
Al-Awali	32	22
Sheib Amir	39	36

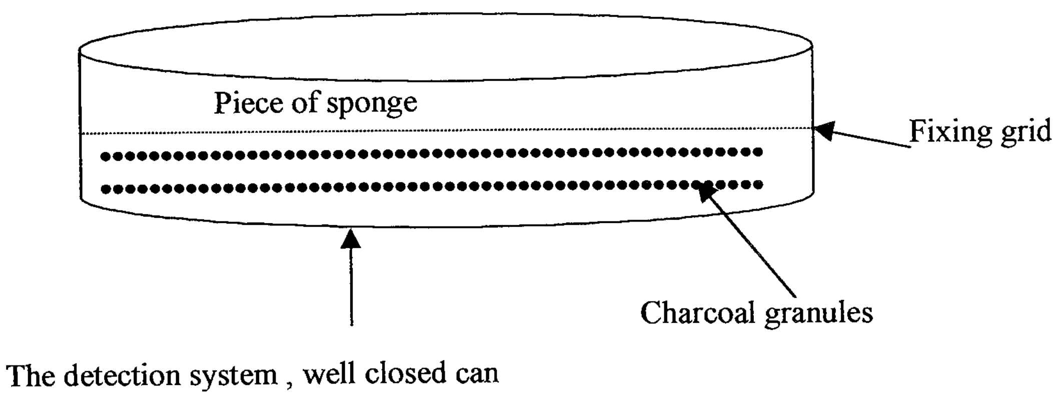


Figure 4-16 Schematic diagram shows the design of King Abdul Aziz University detection system [21]

Table 4-10 : Radon concentration measurements in various Makkah districts

Location	Radon concentration in bedrooms in the summer Bq/m^3
Al-Rosaifah	66
Ajiyad	36
Sheib Amir	36
Al-Otaibyyah	52
Hindaweyyah	56
Al-Aziziyah	54
Al-Awali	22
Al-Misfalah	39
Al-Beeban	14
Al-Sitteen	85
Ree- Al-Kohl	91
Al-Sharaye	77
Al-Zahir	68
Jarwal	65
Al-Nozha	78
Average	**56 ± 23**

Table 4-11 : Radon Measurements in Masher Area

Location	Radon concentration Bq/m^3
Al-Haram	15
Namira Mosque	49
Al-Khaif Mosque	55
Average	**40 ±22**

Table 4-12 : Radon Measurements in The Tunnels

Location	Radon concentration Bq/m^3
King Fahad Tunnel	45
Ajiyad Tunnel	41
Sheib Amir Tunnel	64
Jabal Al-Kaaba Tunnel	67
Al-Moaisim Tunnel	42
Average	**52 ±13**

Table 4-13 : Comparison Between Indoor Radon Concentration in Summer and in Winter

Location	Radon concentration in bedrooms Bq/m^3	
	Winter	Summer
Al-Rosaifah	78	66
Ajiyad	46	36
Sheib Amir	50	36
Al-Otaibyyah	64	52
Average	**60 ± 14.5**	**48 ±14.5**

4-3 Gamma Rays Measurements :

As mentioned before , the equivalent dose radiation due to gamma radiation was estimated using a survey meter that uses Geiger Muller detector . It is designed and calibrated by Nuclear Enterprise to give direct dose rate reading in μSv / hr . Dosimeters are usually used to estimate outdoor radiation levels .

Table 14-4 shows the results . The average value for the equivalent dose rate is 0.25 ± 0.06 μSv / hr . Assuming that ordinary person spends 5 hrs outdoor according to table 3-1 , so the annual effective equivalent dose is :

$$H = 0.25 \times 10^{-6} \times 5 \times 365 = 0.46 \times 10^{-3} \text{ Sv/year} = 0.46 \text{ m Sv/year}$$

Table 4-14 : Gamma Radiation Measurements

Location	Equivalent Dose rate μSv / hr
Al-Aziziyah	0.21
Al-Zahir	0.20
Al-Rosaifah	0.23
Mina	0.22
Al-Haram	0.20
Namira Mosque	0.32
Al-Khaif Mosque	0.25
King Fahad Tunnel	0.31
Ajiyad Tunnel	0.18
Sheib Amir Tunnel	0.30
Al-Moaisim Tunnel	0.36
Average	**0.25 ± 0.06**

4-4 Feasibility Studies :

Some of the characteristics of the SSNTDs was outlined in the third chapter of this thesis , such as its low cost , ease of use , permanence of recorded tracks and insensitivity for moderately high background such as : β and γ radiation . Since this type of detection systems is now well established in our laboratory , so we suggest extending the use of this system to perform alpha particles spectroscopic studies and neutron measurements [48] , [46] .

On the other hand , the present system can be used to perform some important applied studies , such as the inspection of the presence of cracks in the earth crust . Since terrestrial uranium is the main source for radon , so we expect radon concentration to be very high where the presence of cracks is probable . Geologists suspect the presence of cracks in the earth crust in some areas in Makkah such as Sharaye district [47] . This suspicion can be tested if radon concentration is monitored over a long period . Feasibility study for such investigation has been made in Al-Aziziyah . About 500 of the can – technique detection systems used in the present study , was prepared and located inside the large cylindrical container shown in figure 4-5 and was left for

different periods of time in the range 10-35 days . The results are shown in figure 4-17 and tabulated in table 4-15 . It can be seen that that the track density resulting from the radon gas confined in the air of the container increases during the first twenty days and then becomes constant indicating that there is no cracks in the earth crust in that area . If there were any cracks the radon concentration would have continued to increase . We suggest that careful continuous monitoring for the radon emanated from the ground in Sharaye area .

Another feasibility study was made to estimate radon concentration inside houses under ground water reservoir . High radon concentration is expected for the following reasons :

1. It is inside the ground ,
2. It is covered with thick layer of concrete ,
3. It is rarely ventilated .

Some of the detection systems were prepared and fitted inside some under ground reservoirs in some houses far above the water level and left for about 30 days . Radon concentration was then determined . The results are tabulated in table 4-16 . from these data , the average value for radon concentration in the reservoirs is 71 ± 19 Bq / m^3 while the average radon concentration the bedrooms inside the same houses is $46 \pm 17 Bq / m^3$.

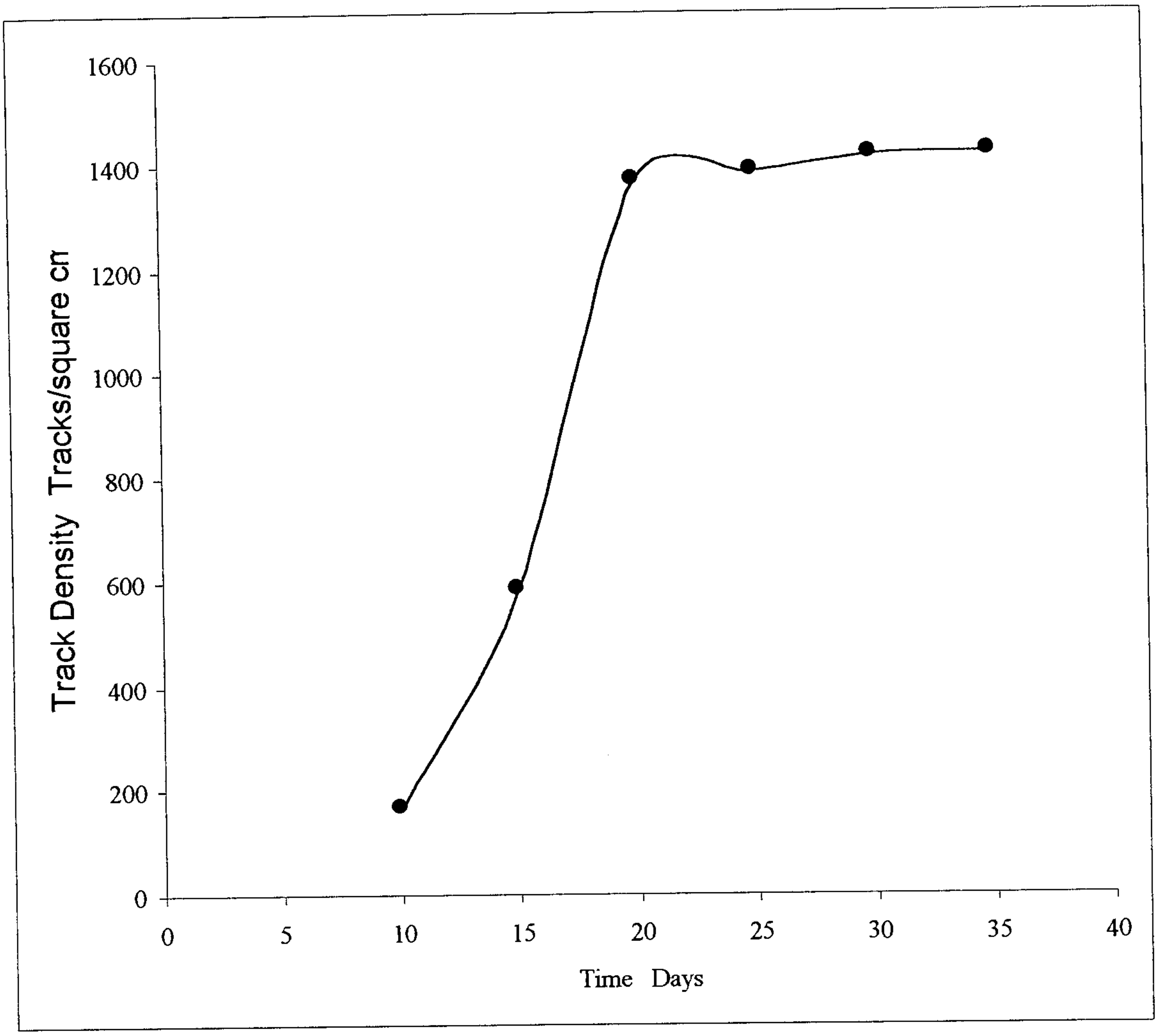


Figure 4-17 : Monitoring of Radon Emanation From the Ground

Table 4-15 : Monitoring of Radon Emanation From the Ground

Time days	Track density Track/cm^2
10	167
15	582
20	1368
25	1384
30	1413
35	1418

It can be seen that radon concentration in the water reservoir is higher than the concentration in the bedrooms of the same houses , but it is not as high as expected. This could be attributed to the fact that the presence of water and water vapor obstruct radon gas from reaching the detectors , radon can be dissolved in the water [44,64] . Thorough investigation can be made and radon measurements in water might be needed .

Table 4-16 : Radon measurements inside ground water reservoirs inside the houses

Location	Radon Concentration Bq/m^3	
	Bedrooms	Reservoir
Al-Rosaifah	66	93
Ajiyad	36	63
Sheib Amir	36	57
Average	**46 ± 17**	**71 ± 19**

Feasibility studies were performed to estimate uranium-238 activity concentration in some kinds of rocks , specially granite , and also the estimation of uranium-238 contents in these rocks . This was done using the method mentioned in chapter 3 and using equations 3-34 and 3-35 . The results of these measurements are shown in table 4-17 . The average uranium-238 activity concentration is 23.7 ± 9 Bq/m^3 and the average uranium-238 content is 1.9 ± 0.7 ppm .

Similar feasibility study was made to estimate radium-226 activity concentration in some samples of the soil , and also the estimation of radium-226 contents in the soil .The results of these measurements are shown in table 4-18.The average radium-226 activity concentration is 49.2 ± 19 Bq/m^3 and the average radium-226 content is 3.9 ± 1.5 ppm .

Table 4-17 : Results of The Measurements of U^{238} in Rocks

Location	U^{238} content in the rocks Ppm	U^{238} activity concentration Bq / kg
Jabal Al-Noor	1.1	13.15
Jabal Thoar	2.3	28.1
Jabal Al-Rahmah	2.4	29.8
Average	**1.9 ± 0.7**	**23.7 ± 9**

Table 4-18 : Results of The Measurements of Ra^{226} in the soil

Location	Ra^{226} content in the rocks Ppm	Ra^{226} activity concentration Bq / kg
Arafat	4.2	53
Al-Sharaye	5.2	66
Al-Aziziyah	2.3	29
Average	**3.9 ±1.5**	**49.2 ±19**

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